THE ECONOMICS OF PURCHASING PRODUCTION MACHINERY.

Paper presented to the Institution, Coventry Section, by
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THE whole object of purchasing production machinery is to produce components of the right quality at the lowest price, comparable with high wages. This ideal is not achieved merely by accountancy or by purchasing the best machines available. There are other important factors which must be taken into consideration such as the design of the components, maximum and minimum sizes, quantities, finish, accuracy, tool equipment, handling facilities, etc. Whilst I do not wish to minimise the importance of cost analysis, it is clear that savings are not made by accountancy however elaborate it might be, but, by purchasing the right machines and tool equipment and what is just as important, to service them in such a manner, that machining time is a maximum and waste time a minimum. The waste time in most factories is more important than the machining time.

Design of the components to be machined affects production costs to such an extent that it will be worth while to spend a few moments considering those factors which have to be taken into account when purchasing production machinery. Preliminary designs, particularly for quantity production, should be submitted to the Planning Operation office, as it will be their job to decide on the machining operations, jigs, tools, and fixtures required. They are familiar with the machine tools available, and they may be able to suggest modifications to the component, which will enable it to be produced more cheaply.

Tolerances.—Too fine a tolerance does not necessarily improve the quality: it increases manufacturing costs, and in the event of purchasing a machine, a more expensive machine may be necessary, or perhaps an additional machine may be required to obtain the accuracy required. The larger the tolerance, the smaller the scrap, and the cheaper the cost.

Finish.—A fine finish usually means additional operations, smaller feeds on lathes, boring machines, and millers, also increased production times on grinding machines, as free cutting wheels cannot be used.

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Quantities.—This is very important when a new component has to be machined. It is not sufficient to state the first ordering quantities—some idea of the sales forecast should be given. No cost analysis can be made unless the quantities are known. If the quantities be large enough, all machining operations might be reduced or eliminated by the use of die castings, brass stampings, or steel pressings.

Materials.—Free cutting ferrous and non-ferrous materials should be used wherever possible. Compare for example the difference between the production times and tool maintenance of machining phosphor bronze and gun metal bushes, yet this latter metal may be quite suitable. Very often more money can be saved in the design office than in the machine shop.

The first step in the purchase of production machinery is obviously to obtain sufficient data regarding the components to be machined, their maximum and minimum sizes, tolerances, finish, quantities, material, etc., and yet I think that everyone concerned with the purchase or supply of production machinery will agree with me that it is usually more difficult to obtain that data than to decide on the right machine.

Detailed consideration of the Machine.—Having obtained the requisite data regarding the components to be machined, the next important step is to determine the capacity of the machine. Do not request machines of too large a capacity ; the initial cost is greater ; the tool equipment costs more ; they take up more floor space ; they are usually more tiring to operate, and the price per piece is often increased. Consideration should be given to large machines in other departments, as it may pay to re-route the work, particularly if the percentage of work be small. Space must be allowed for withdrawing shafts for repairs.

Home Office and Safety Regulations must be rigidly adhered to. Fan exhausting plant is required for dry grinding machines, cellulose spraying, machining asbestos, etc. The cost of this equipment must be included in the capital outlay for the machinery or plant. It is not sufficient to purchase a machine and install it in any vacant space in the machine shop, it may be advantageous to move other equipment, in order to obtain the maximum efficiency from the machine. The cost of re-arranging other machines for this purpose, must not be added to the capital outlay, but charged to shop expense.

All machines should be purchased of sufficient power and rigidity for the use of tungsten carbide tools. It will not be possible to-night to discuss every type of machine, therefore reference will be made to machines which are common to most factories. These will be dealt with in the following manner : (a) Points to be taken into

consideration when purchasing machines; (b) Accountancy, or, Will it pay?

Drilling Machines.

Drilling time is usually such a small percentage of the floor to floor times, that the slogan for drilling machines should be "Avoid waste time." Increased speeds and feeds, although important, are not sufficient reasons in themselves for requesting a new machine. An old machine may drill a hole in one minute, and a new machine in half a minute, thereby reducing the cutting time by 50%, but the setting time, particularly on large machines, may be five minutes and probably fifteen minutes if waiting for a crane lift. Five or fifteen minutes setting time, is much more serious than losing half a minute in drilling time by using an old machine, more than one hole may be drilled at one setting, even then the proportion is high.

Probably the provision of a jib crane at the cost of £50 would double or treble the output of a drilling machine costing £500. Quick change chucks should be used to facilitate drill changing. There is no doubt that the time will come when they are an integral part of every drilling machine. Multiple drilling heads should be used when the quantities warrant it.

Sensitive Drills.

If the holes to be drilled are under ¼ in. diameter a high speed sensitive drill is required. The usual type of sensitive drills used in engineering shops have a capacity of [illegible] in. diam. in m.st. on the plain spindle and 1¼ in. dia. on the geared spindle. These maximum sizes are for occasional use, ⅝ in. and 1 in. respectively are quite large enough for normal use. Modern machines are arranged for self-contained motor drive, with a rotor and stator unit on each spindle, operated by a change pole switch. Various speed ranges can be provided, make sure that they are suitable for the size of holes to be drilled, and with a multi-spindle machine, each head could have a different speed range, and don't forget the geared spindle for the large holes and the reverse for tapping. Automatic feeds can be provided for about £10 per spindle.

Light Radial Drilling Machines.

On a modern light radial, the drill can be so expeditiously moved from one hole to another, that it may pay to purchase a machine for this reason alone.

Automatic Drilling Machines.

Should be purchased where quantities warrant it.

Radial Drills.

These can be purchased as light, medium, or heavy, therefore don't waste money by buying a heavy machine if a light one will fill the bill.

A modern radial with centralised control is so easy to manipulate, that I cannot imagine a radial, built ten or fifteen years ago, that it could not efficiently replace.

Full use should be made of multiple tables. It is not necessary for identical work to be put on the four tables, in fact, it is usually preferable to have different kinds of work to balance the setting time of the driller's mate.

Pillar Drills.

Quick operated tables are now fitted, to expedite moving the work to the drill.

Turret Lathes for Chucking Work.

If the general run of work comprises chucking jobs, and the chucking time is a large percentage of the machining time, then an air chuck is desirable ; if the work be fragile, the air chuck should be arranged for high and low pressures. If all the work be chucking of say 6 in. to 24 in. diam., a chucking lathe is sometimes preferable to a turret lathe, it is much cheaper and takes up less floor space. On quantity jobs, cutting by several tools at one time by the turret lathe, should be carefully compared with the chucking lathe. Large holes should not be drilled on a turret lathe, as with the fine feeds required, the slipping clutch will not operate, and serious damage or high maintenance costs will accrue. Where work has large holes, the first operation should be on a drilling machine, preferably located by the side of the machine for sawing off the bars.

Turret Lathes.

A turret lathe is essentially a multi-cutting machine, and as many tools as possible should be cutting at one time, certainly more than one. Work of similar diameter should be chosen, length is not so important ; it is quicker to alter length stops than roller steadies. It sometimes pays to have a set of roller steadies on the tool rack, set to different diameters. Don't spend £1,000 on a turret lathe and make it inefficient by not having sufficient tool equipment. The tool equipment for a turret lathe can easily reach a figure equal to 50% of the price of the machine.

Boring Mills.

Most work up to 24 in. diameter can be done more cheaply on a turret lathe or chucking lathe, if for no other reason than that a

boring mill has to be stopped for sizing the work. Above this size, a modern powerful boring mill should easily show savings over lathes. Boring mills take up comparatively little space and the work is readily put into the machine. A jib crane saves setting time. A Duplex mill is useful for two operation jobs. A side head looks attractive on paper, but it is not always an economical proposition. When considering replacing large boring mills, it may be that the work itself is not rigid enough to use the increased speeds and feeds obtainable on modern machines, although an advantage might be gained by using tungsten carbide tools.

Milling Machines.

When purchasing a milling machine make sure whether it will be used for heavy or light milling. If used for quantity production, perhaps a cheaper machine could be bought with pick-off gears instead of a speed or feed change gear box. Rigidity is essential, not only in the machine itself, but in the milling fixtures. Considerably increased output can be obtained from milling machines by ensuring that the cutter is properly ground, the cutter and arbor run true, the arbor support is close to the cutter, and the non-moving slides clamped. These are obvious points, but they often are not faithfully carried out, consequently, the output goes down and the maintenance goes up. An indexing table on a horizontal milling machine at the cost of £85 might save the cost of an additional milling machine costing £850, for if the work be suitable, an indexing table will often reduce the floor to floor times by nearly 50%.

It is well worth the additional expenditure on intermittent cutting stops for milling pads on castings. These intermittent cutting stops are often used in conjunction with multiple jigs, sometimes quite wrongly for this purpose, as it is usually quicker to have an indexing fixture for two components, the one being milled, whilst the other is being inserted in the jig, whereas a multiple fixture wastes considerable time in loading. When purchasing vertical millers, a circular table often pays for itself.

Grinding Machines.

It would be impertinent for me to comment on grinding machines in Coventry, for such excellent machines have been demonstrated during the last few years at the firm with which your chairman is associated, Messrs. Alfred Herberts, that I am sure most people in this room are familiar with them. There are, however, two comments worth making. First, surface grinding may be a much cheaper proposition than milling, particularly on fragile work; second, the majority of flat work filed in a vice can be expeditiously ground on a vertical spindle grinder with the flat grinding face

uppermost. There are many other machines on which comment could be made, such as planers, presses, moulding machines, etc., but we must leave time to discuss accountancy.

Accountancy—or Will it Pay ?

When all the factors are taken into consideration, and it is decided which machine to buy, then comes the acid test, will it pay ? There are four primary ways of spending money on production machinery. First, expense ; second, replacement ; third, additional equipment ; fourth, development. It is very important that money spent on production machinery should be allocated to the right category, or considerable money will be lost to the company, if items which are legitimately expense are placed to a capital account which is taxable. We can rely on the accountants taking care of this, and my only excuse for mentioning this subject is that other executives who are responsible for spending money, should be cognisant of its importance.

The actual wording of an order may—from an accounting point of view—make it capital or expense.

Expense.

Naturally every works manager incessantly hammers at his shop superintendents to keep their expense items to an economic minimum. The words " economic minimum " are used deliberately, for every alert superintendent is constantly improving the production methods in his factory, these cost money, but this money should be recovered on the botton line of his trading account, e.g., I saw recently a power press where the output was nearly doubled by improving the method of feeding the blanks, and in another case the output of a department increased by at least 15% by improving the working condition of the operators. Expense items of this kind are obviously justifiable.

The following is a summary of items which should be placed to the expense account : (*a*) Repairs to machines ; (*b*) reconditioning machines ; (*c*) spare parts of all kinds, such as shafts, gears, bearings, etc., some accountants would include items such as spare motors in the expense account ; (*d*) replacement of any part of a machine ; (*e*) additional tool equipment, if not ordered within twelve months of the installation of the machines.

Regarding item (*b*), the reconditioning of a machine by your own firm or by a firm of machine tool makers is expense. The purchase of a reconditioned machine is capital, because the capital assets of the company are increased.

It is obviously in the interests of the company to charge as much as is legitimately possible to expense, otherwise income tax will be chargeable, and the capital assets will be unduly inflated. It

is sometimes argued by shop superintendents, that although it is in the interests of the company to overhaul a machine, it is distinctly unfair to debit them with the expense, as it would be better for their trading account if a new machine were purchased. This is not so, if a machine were overhauled, the expense item only occurs once, whereas if a new machine were bought, interest on capital, depreciation, and income tax, would be charged over a number of years. As a matter of fact, even if a machine were thoroughly overhauled, the expenditure would not, as a rule, be so much as that required to cover the first year's payment for interest on capital, depreciation, and income tax.

Replacement of machine tools is without doubt the most important item of expenditure on plant in any machine shop. Systematic replacement of obsolete and worn out machines is essential, if machining costs are to be kept to a minimum. There are many ways of estimating savings, by replacing machine tools, but they are all variations of the following methods : (1) Multiply the machine hour rate on the old and the new machines respectively by the floor to floor times (including setting times) per year. The difference between these two figures is the savings in factory cost per year. The machine hour rate method is an attempt to find the true costs of running a machine, by taking every item of the oncosts, and allocating these individual costs, at their correct figure per hour, to the machine.

The machine then bears its correct portion of rent, rates, taxes, supervision, lubricating oils, transport, heat, light, ventilation, power, tool cost, depreciation, interest, labour, etc. This is the ideal, and various compromises are made, by giving *pro rata* figures for some items, and individual figures for other items. In spite of the fact that it is difficult and costly to obtain accurate data, the machine hour rate method has many adherents, at least in theory, because it is a real effort to obtain true costs. Exhibit I shows an actual example of savings worked out by the machine hour rate method ; this example was kindly supplied by Messrs. William Asquith & Co. Ltd.

EXHIBIT I.—An actual example of costs and savings resulting from the installation of a 4 ft. radial drilling machine to replace 3 ft. 6 in. belt driven machine of another make.

(1) Hourly costs of new machine and belt driven machine of another make.

	New machine £	s.	d.	Old machine £	s.	d.
Capital cost of machine at	420	0	0			
Foundation (alteration to old foundation)	3	0	0	Written		
Erection	3	0	0	down to		
Wiring	5	0	0	residual		
				value		
	431	0	0			
Residual value	80	0	0			
Net amount for depreciation	351	0	0			
Life of machine before it becomes obsolete, assumed ten years :—						
(a) Charge for depreciation... ...	28	7	6	Nil		
(b) 5% interest on first cost ...	21	11	0	Nil		
(c) Shop charge for floor space occupied by machine and its work, 50 sq. ft. at 9d.	1	17	6	1	17	6
(d) On cost—9d. per hour—2350 hours yearly	88	2	6	88	2	6
(e) Power at 1.1d. per unit to cover for electrical maintenance ...	8	0	6	22	18	3
(f) Machine maintenance	3	0	0	6	0	0
(g) Tool maintenance	6	10	0	5	0	0
(h) Wages—50s. weekly	125	0	0	125	0	0
For 2350 hours yearly ...	282	9	0	248	18	3
Total cost per hour	0	2	5	0	2	1½

Savings.

Observed floor to floor times with the original machine and the new 4 ft. machine were as follows :—

		Old machine Time min.	Old machine Cost pence	New machine Time min.	New machine Cost pence	Saving pence	Saving % Original cost
Sluice valve cover	8 in.	18	7.6	7	3.4	4.2	55%
	9 in.	20	8.5	10	4.8	3.7	44%
	12 in.	26	11.0	12	5.8	5.2	47%
	14 in.	30	12.7	13	6.3	6.4	50%
Sluice valve body	12 in.	65	27.6	36	17.4	10.2	37%
Weir plate	...	4 hrs.	8/6	1 hr. 40 min.	4/0½	4/5½	52%
Penstock	...	4 hrs.	8/6	1 hr.	4/0½	4/5½	52%
		10 hrs. 39 mins.		4 hrs. 38 mins.			

In one week of forty-seven hours, the new machine produces work that previously took 108 hours.

The comparative costs for the week's output are :—

		£	s.	d.
Old machine.	108 hours at 2s. 1½d.	11	9	6
New machine	47 hours at 2s. 5d.	5	13	6
Weekly saving of new machine		£5	16	0

This machine wipes out its cost in seventy-five weeks, and the cost of drilling work is reduced to 49% of its previous figure.

Multiple Setting.

An analysis of the production time on the jobs observed, shows that if multiple setting were adopted the floor to floor times would be reduced to 60% of the times with the single setting of 4 ft. Under these conditions the cost per hour of the machine with driller and setter would be 3s. 6d., and the cost of one week's work would be £8 4s. 6d., whereas this work would cost £19 2s. 6d. if done by the other type. The estimated cost of the multi setting 4 ft. would be repaid in forty-five weeks and the cost of drilled work reduced to 43% of its old figure.

The machine hour rate method has many pitfalls. It is clear that the ideal machine to which this method can be applied, is one on which the same type of component is being machined, year in, year out. Immediately different types of components are

machined, the individual items of oncosts vary, thus upsetting the true machine hour rate., e.g., tool costs vary with the material being machined; supervision, shop clerks and labourers, differ with small and large quantities, etc.

Machine Hour Rate.

To obtain the cost in pence per hour to operate any machine, the following factors must be taken into consideration : (*a*) Capital charges ; (*b*) cost of floor space ; (*c*) power ; (*d*) maintenance of machine ; (*e*) tool maintenance ; (*f*) labour ; (*g*) oncosts.

These items can be determined in the following manner :—

(*a*) *Capital charges.* These include the interest and depreciation on the actual cost of the machine, complete with its foundations, wiring, installation, standard tool equipment bought with the machine, testing out the machine, and putting it into operation.

There is a divergence of opinion by accountants as to whether interest and depreciation should be on the gross or net capital investment, and the following three methods are in use :—

(1) Subtract the re-sale value of the old equipment from the investment in new equipment.

(2) Subtract the residual value of the new equipment from its original cost.

(3) Total capital investment without any subtraction.

There is a good deal to be said for the third method, from an accounting point of view, for something tangible is being used. It may be that the old machine has to be sold below book value, on the other hand it may be fully depreciated. The charge for interest should be about 5%.

The depreciation or wear and tear allowances for taxation purposes, are a matter for agreement with the Commissioners of Inland Revenue, and varies according to the nature of the industry, and for the type of production machinery we are discussing tonight, is generally speaking about 7½% plus an additional 10% allowance under the Finance Act of 1932, making the present allowance of approximately 8¼%.

In addition to the wear and tear allowance, the Inland Revenue grant an obsolescence allowance where a machine is scrapped and *replaced*. This obsolescence allowance is the difference between the first cost of the machine less the amount of the wear and tear allowance which has been allowed, plus any sale or scrap value of the machine.

The depreciation for our purpose should not be less than this, some firms prefer to fully depreciate plant in ten to fifteen years. A straight line depreciation of approximately $7\frac{1}{2}\%$ per annum would fully depreciate the cost of a machine in fourteen years, other firms by the reduced value or Inland Revenue method of so much per cent per annum; the machine by this method is never fully depreciated.

(*b*) *Cost of floor space*. This is obtained by finding the total cost for maintenance of the building, rent (or its equivalent), rates, taxes, heating and ventilating, multiply this cost by the area occupied by the machine, together with the space allowed around the machine for efficient working, and divide by the total area of the building. If a machine is purchased which replaces any three old machines, the available floor space has to be paid for, and can only be taken care of under the item oncosts, which in turn slightly affect the machine hour rate of all the other machines.

(*c*) *Power*. Personally, I don't see how any accurate figure can be given, except by taking watt meter readings throughout the year for the old machine; it could not be obtained on the new machine. The power will vary with the diameter of the work, the material being cut, the sharpness and shape of the tool, the period of activity, setting times, etc. The nearest figure that can be obtained is by taking the total power consumption per year, in a particular shop using similar machines, divide by the total rated h.p. of the motors; this will give an efficiency factor per h.p. Multiply this figure by the h.p. of the motor on the machine under consideration.

(*d*) *Maintenance of Machines*. This can be obtained by experience on similar machines. The average maintenance of a new machine will be less than on old machines, owing to the use of ball and roller bearings, heat treated gears, covered beds, etc. The cost of maintenance depends to a large extent on the limits of accuracy required on the components being machined.

(*e*) *Maintenance of Tools*. This covers re-grinding and replacement of drills, reamers, cutters and bars, tools, etc., and is estimated by past experience.

(*f*) *Labour*. This is the actual money paid to the operator including cost of living bonus, but not including overtime or shift premiums, as these are expense.

(*g*) *Oncosts*. What is this mysterious item? An excellent example of how these should be determined is given in that famous book "How to Run a Bassoon Factory."

	s.	d.
Wood for bassoon	0	4
Metal for bassoon	0	5½
Reed for bassoon	0	0½
Making bassoon	7	6
	8	4

Actual cost of bassoon : £29 9s. 6d.
Then the difference of : £29 1s. 2d. is the overhead costs.

There is a good deal of truth in this humorous analysis, for if we subtract the direct labour and material from the actual cost, the remainder is the oncosts, no item however small can be omitted. Oncosts can be divided into a large number of items, probably a hundred, and it is essential to divide oncosts into a large number of items to see where the money is being spent, also, it is imperative that the management, supervision, and inspection have copies of this analysis every month, otherwise, they cannot control the expenditure.

Under the item of oncosts must go all the remaining costs, such as non-productive labour, shop clerks, lubricants, etc. When there is a choice of two machines there is a tendency to put the work on the machine with the lowest hour machine rate. This should be done only after considering the true cost. As a rule, a similar machine with a high machine hour rate will give lower costs, because of the reduction in time to do the work. e.g., if a machine were rated at 5s. per hour and a similar machine 3s. per hour, and the former machine produced the work twice as quickly, the higher rated machine would give lowest costs, and in addition quicker delivery time. When determining labour costs the efficiency factor must be included.

It would be easy to prove that the actual cost of running a machine varies from hour to hour, therefore I cannot see how a machine hour rate can be fixed except over average conditions. There may be a simple way of establishing a machine hour rate, with varying costs, if so, I should like to hear of it.

Method II.

It is frequently stated that the total savings from a machine can be obtained by multiplying the direct labour savings by the establishment charge. This is obviously incorrect, as the savings by this method would be the same whether the machine cost £10 or £10,000, also there may not be a gain by establishment charge.

Let us compare an old machine, and a new machine which can produce the work in half the time, old machine fully depreciated.

Exhibit II.

	Old Machine			New Machine			New Machine		
Activity of Machine	100%			50%			100%		
Number of articles produced per year	1,000			1,000			2,000		
	£	s.	d.	£	s.	d.	£	s.	d.
Labour	125	0	0	62	10	0	125	0	0
Material	250	0	0	250	0	0	500	0	0
Overheads 150%	187	10	0	187	10	0	187	10	0
Depreciation and interest on machine	0	0	0	62	10	0	62	10	0
Total Cost	562	10	0	562	10	0	875	0	0

In this case, the new machine would not show any saving if the same quantity of articles were required, but if it replaced two machines, the savings would be £250 per annum.

Exhibit III shows another method of the cost comparison between an old and a new turret lathe.

Exhibit III.

Value of existing machine and tools £185.	Value of new machine and equipment £700.
Production time thirty minutes.	Production time fifteen minutes.
Machine depreciation life ten years.	Machine depreciation life five years.
Operator's wages 1s. 6d. per hour.	Operator's wages 1s. 8d. per hour.
Works overheads 150%.	Works overheads 160%.
Thirty minutes at 1s. 6d. per hour 9d.	Fifteen minutes at 1s. 8d. per hour 5d.
Depreciation of machine per piece= $\frac{\text{£185}}{\text{10 years of 50 weeks of 45 hours.}}$	Depreciation of machine per piece = $\frac{\text{£700}}{\text{5 years of 50 weeks of 45 hours.}}$
=2d. per hour.	=approx. 1s. 3d. per hour.
∴ $\frac{30}{60}$ of 2d., 1d.	∴ $\frac{15}{60}$ of 1s. 3d., 3¾d.
Overheads 150% on labour 1s. 1½d.	Overheads 160% on labour 8d.
Cost per piece 1s. 11½d.	Cost per piece 1s. 4¾d.

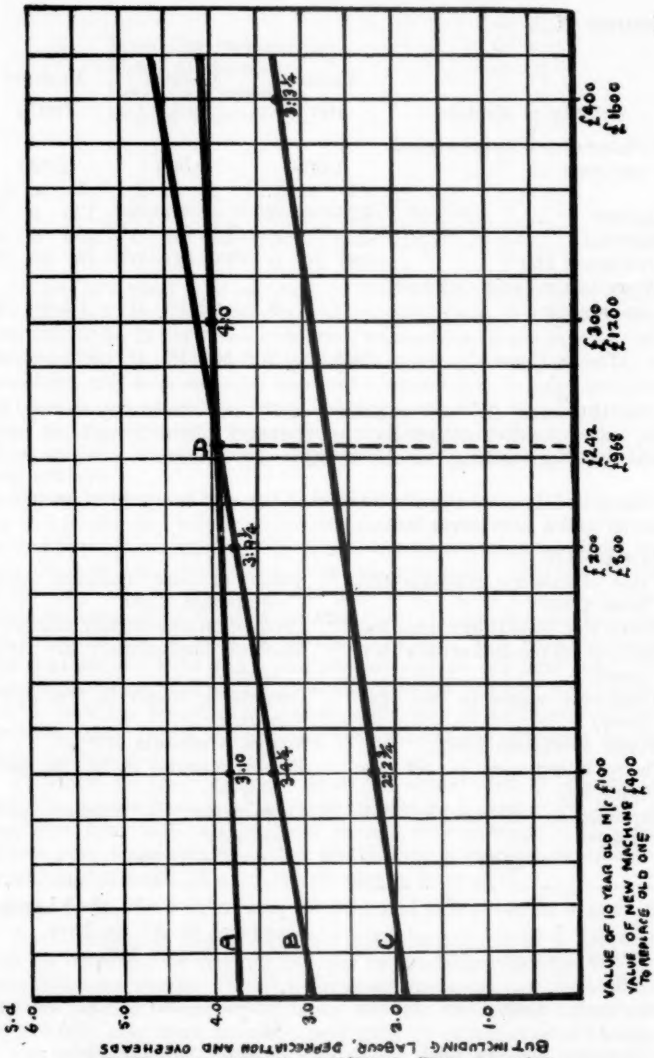
COST PER PIECE EXCLUDING MATERIAL AND PROFIT
BUT INCLUDING LABOUR, DEPRECIATION AND OVERHEADS
s.d
6.0
5.0
4.0
3.0
2.0
1.0
A
B
C
3.10
3.4¼
2.2¼
4.0
3.3¼
A
VALUE OF 10 YEAR OLD M/c
VALUE OF NEW MACHINE TO REPLACE OLD ONE
£100
£400
£200
£800
£242
£968
£300
£1200
£400
£1600

Exhibit 5.

Exhibit IV shows the comparison of profit of these old and new turret lathes.

Exhibit IV.

Old Machine.			New Machine.		
Production per forty-five hours =90 pieces.			Production per forty-five hours =180 pieces.		
Cost per piece ...	1	11½	Cost per piece ...	1	4¾
Cost of material per piece	1	6	Cost of material per piece	1	6
Profit per piece ...	0	6½	Profit per piece ...	1	1¼
Selling price ...	4	0	Selling price ...	4	0

Profit on 180 pieces at 1s. 1¼d.=£9 18s. 9d.
,, 90 ,, ,, 6½d.=£2 8s. 9d.
Increase in profit per week = £7 10s. 0d.

Exhibit V is a graph plotted from a number of instances similar to that shown on Exhibit II.

This graph can be utilised for the consideration of any machine tool irrespective of type. The vertical line indicates the cost per piece including operators wages, depreciation and overheads, but excluding cost of material and profit.

The horizontal scale gives the price of existing machines at their depreciated value, and also the cost of new machines at four times the price of existing machines.

Line A indicates the calculated cost of production on the old machine. Line B the cost per piece assuming a 33⅓% time reduction as against A. Line C the cost per piece on a 50% time reduction.

The point D indicates that a machine and equipment depreciated to £242 can be replaced by a machine and its equipment and valued at £968, the cost per piece being equal. Any machine valued less than £242 could be replaced with advantage by a new machine.

With regard to a 50% saving, line C would not cut line A until the figures were in the region of £800 for the depreciated value of an old machine which could then be replaced by a new installation valued at £3,200.

The comparison of the turret lathe and the very useful graph were kindly prepared by Mr. E. W. Field, technical manager of Messrs. H. W. Ward & Co. Ltd., Birmingham.

Here is an example of American practice which is a slight variation of method 2.

Exhibit VI.

The analysis of costs by this firm are interesting, as they have practically no quantity production. Their basic condition is, that

the replacement of any machine shall show a net profit return after depreciation, of at least 20% per annum on the net investment. Such equipment will repay for itself in thirty months or two and a half years.

The following is a copy of Messrs. Warner and Swasey's Equipment Replacement Statment :—

WARNER & SWASEY EQUIPMENT REPLACEMENT STATEMENT :—

Average former cost 56.1 minutes (per piece) × $2\frac{1}{2}$ cents (with direct labour at 60 cents and overhead at 90 cents, a total of \$1.50 per hour or $2\frac{1}{2}$ cents per minute).	1	40
Average cost with new equipment 40.1 minutes (per piece) × $2\frac{1}{2}$ cents.	1	00
	—	—
Savings per piece		40

Production per month with new equipment.

60 minutes (per hour) × 9 hours (per day) × 23 (working days) = 314 pieces.

40.1 minutes per piece (with new equipment).

Total savings per month will then be :—

314 (pieces per month) × 40 cents (savings per piece)	125	60
If the new equipment is kept busy only 80% of its time deduct 20% for idle time.		
20% of \$125.60 (savings per month)	25	12
Value of usable savings per month	100	48

Investment in new equipment	3	915	00
Less re-sale of old equipment	1	850	00
Net cash investment on new equipment.	2	065	00

The new equipment will pay for itself in :—

$$\frac{\$2065.00 \text{ net cash investment}}{\$100.48 \text{ (usuable savings per month)}} = 20.6 \text{ months}$$

The nett profit return per year will be :—

\$100.48 (usable savings per month) × 12 months	1	205	76
Less 20% depreciation on \$2065.00 (net cash investment)		413	00
Net profit per year after depreciation		792	76

The rate of nett profit will be :

$$\frac{\$792.76 \text{ (the net profits)}}{\$2065.00 \text{ (nett cash investment)}} = 38.4\%$$

The average costs were obtained by taking 12 different types of work, including chucking work on cast iron, forgings, and steel. It will be noted that interest on investment is not taken into account. This was ignored because the increased percentage of time to recover the investment was so small.

We will check this against the turret lathes which we have just considered. Total charge for interest was figured as follows :—

$$\frac{\text{20.6 months to repay}}{\text{12 months per year}} \times 6\% \text{ interest per year} = 10.3\% \text{ of investment.}$$

As the investment is being reduced month by month, the average interest over the whole period (not per annum) is 5.2. In other words, the total interest charge for the entire period was 5.2 of the investment of $2,065.00 or $107.38. Since the machine is saving $100.48 per month, as shown by the statement, this would add to the time of repayment.

$$\frac{\text{\$107.38 total interest on investment}}{\text{\$100.48 usable savings per month}} = \text{1.1 months}$$

If the period of time to repay were longer, the interest on capital would be more noticeable—on the other hand, if say 10% per annum were allowed for depreciation, the net profits would increase year by year, because 10% would be subtracted each year from the net investment, thereby reducing the ratio of $\frac{\text{usable savings}}{\text{net investment}}$ which equals the rate of net profits.

New equipment which will show a 20% return after depreciation of 20% on the investment, will pay for itself in thirty months or two and a half years.

e.g.—Investment in new equipment	= £3800
Less re-sale of old equipment	= 800
Net cash investment of new equipment :	£3000

New equipment will pay for itself in :

$$\frac{\text{£3000}}{\text{£100}} = \frac{\text{net cash investment}}{\text{usable savings per month}} = \text{30 months.}$$

Net profit return per year will be :

£100 (usable savings per month) × 12 months	= £1200
Less 20% depreciation on £3000 (net cash investment) =	£600
	£600

The rate of net profit will be :

$$\frac{\text{£600 net profit}}{\text{£3000 net cash investment}} = 20\% \text{ per annum.}$$

The time required for a machine to pay for itself, for any other percentage of profit, can be found by using the same formulae.

The S.K.F. Co. of America, who make precision parts in quantities, have by their replacement policy doubled their output in the same floor space in ten years, as well as improving the quality and finish of their ball and roller bearings. In considering the advisability of the purchase of replacement equipment, they set two years as a satisfactory period to accomplish the return of the additional investment. This is considered in hours of operation for regular day shift work. They replace equipment to a formula, which in principle is the same as Messrs. Warner & Swasey's, except that it includes raw material being machined. This may involve not only more or less raw material used by the machines compared, but the increased or decreased scrap.

The S.K.F. formula is as follows :—

$$M = \frac{Ce + Ct + Vb}{(Rp - Re)\,N \times Dm - T}$$

Where M = number of months in which equipment will pay for itself through savings.

Ce = Cost of new equipment installed, including carriage and foundations.

Ct = Cost of new tools, jigs, and fixtures, required to operate the equipment.

Vb = Book value of replaced machine minus second hand or scrap value realised.

Rp = The estimated material, labour and overhead cost per piece on present equipment.

Re = Ditto proposed new equipment.

N = Number of pieces to be produced per day by the proposed equipment.

Dm = Number of working days per month.

T = The interest per month on capital investment.

The information referring to Messrs. Warner & Swasey's method of replacement of machine tools, was extracted from an article in *The American Machinist*, dated January 9, 1932, and the one by Messrs. S.K.F. Co. in the December 26, 1931, issue of the same journal. This information has been given by kind permission of the editor of *The Machinist*.

Additional Plant.

This is required to cater for increased production. Comment need not be made on this, as machine cost analysis has already been discussed.

Development.

Machines are bought under this category, when a new line of manufacture is developed. This capital expenditure, together with all the other expenditure on development such as jigs and special equipment, is gradually liquidated by dividing the total cost by the total number of pieces, which it has been decided to make in a given period of time, e.g. : If £10,000 were spent on development of a new line of apparatus, of which it was estimated that 20,000 would be sold per year, and the total expenditure had to be liquidated in two years,

$$\text{then : } \frac{£10{,}000}{20{,}000 \times 2 \text{ years}} = £\tfrac{1}{4}.$$

This sum of 5s. would be added to the manufacturing cost of each piece of apparatus. Machines bought would be fully depreciated on the books of the company, but they would be treated, for taxation purposes, as if charged into the capital account, no further relief being obtained from the Inland Revenue authorities, because the plant was bought on development.

How much money should be spent on Replacement per year ?

Not less than the amount allowed by the Inland Revenue authorities for depreciation of plant. Not more than the amount allowed on the balance sheet of the company for the same purpose. At least 90% of this latter amount should be available for replacement, and out of this 90%, a sum of money should be set aside, so as to replace large and expensive machines, which only require replacing after a number of years.

Let us suppose that a large boring mill required replacement at a cost of £10,000. It is not reasonable that the majority of the money available for replacement in one year, should be swallowed in one item ; this would not happen if each year a sum of money from the depreciation account were set apart for this purpose. Similar budgets should be established for repairs to buildings, etc.

Income Tax Allowance for Depreciation of Machinery and Plant.

My opinion is that the income tax authorities should increase the allowance for depreciation of machinery and plant, on condition that proof were forthcoming that a prescribed capital expenditure

had been made on replacement to plant. The actions and reactions of this policy are not so simple as they look, but it would be a progressive policy towards increasing the efficiency of the plant in this country; it would improve the machine tool business, and the Chancellor of the Exchequer would not lose in the long run. It is not the amount of money in circulation which makes prosperity, but the speed at which it circulates.

Discussion.

Mr. Ackerley : In view of the extreme shortage of skilled labour don't you think proper consideration ought to be given in the selection of machines to the type of labour you would want for the machine ? We, ourselves, have proved many times by putting a foolproof machine on to a certain job we can use unskilled labour on it, and thus save our skilled labour for other jobs. I think this is an important point—that when selecting machine tools care should be taken to see they are suitable for the type of labour available. I would like to have Mr. Wray's views on this.

Mr. Wray : I haven't an idea of the type of machine Mr. Ackerley has in mind, but I do think it is the duty of Mr. Drane and his colleagues to make machines which can be operated less and less by skilled labour. To-day many turret lathes can be, and are, operated by girls quite as effectively as by men. A good deal of this, of course, has to do with the training, and the same sort of problem is occupying the engineers to-day in Germany. This is how one German firm is tackling the problem. They are training their boys as mechanics, and they have to sit for an examination regularly on their practical training, and they not only get marks on it, but as they go along, their pay depends upon it. I think there is a good deal in that idea. In this country we do practically nothing to train our boys. We stick them on a machine and there they just rub along.

I don't think on the ordinary machining operations in any engineering shop they require very high skill, as, for instance, they did in my own apprenticeship days. When I was an apprentice, we used to know that we must move the tailstock of a lathe one way, or something else another, and altogether there was a great deal more attention needed to obtain accuracy. To-day, you insert your work in the machine, press a lever, and you know it will be parallel.

Mr. Scaife : I should like to make one point clear. Mr. Ackerley means something of this sort, and perhaps Mr. Wray has not just answered it. The point Mr. Ackerley makes was, I think, this. Take an internal grinding job. You might have a plain internal grinder operated by a highly skilled man, for if accurate sizing had to be obtained, it would need a highly skilled man because the features are not on the machines. Then take a more expensive machine, on which the sizing would be done automatically. You can get the same accurate results from this machine even when operated by unskilled men.

Mr. Cole: I made one or two notes during the lecture that I would like just to mention. I think in the early part of Mr. Wray's lecture he mentioned the question of tolerance and the importance of widening tolerances, to give us lower costs. My own observation on this point is that I do feel a free hand should be given to the designer, and if he knows his job I think it is up to the production engineer to work to the design. Very often the changing about, and swapping of tolerances, has a very detrimental effect on the work being made. Another point I thought about was—I didn't know Mr. Wray had made reference to the universal nature of the machine tools one is buying to-day. This is an important point, because very often the production engineer can be led astray by specialised machines. I have found in the past this point has not been sufficiently looked into, and before the production engineer has known where he is he has found that machines which have been bought for specialised work have never been required, because the special parts have not been required. The universal nature of machines being bought should be taken into account. As to return on investments. The American firm making the bearings worked on a theory of return on investment in two years. I don't know how long they intended that to apply. Certainly there might have been room for such a plan from 1918 to 1935, but during the last few years we have made very rapid strides.

Mr. Wray: I agree that the question of tolerances applied to the designs side rather than to the shop side. I said this for a definite purpose; I wanted to emphasise the fact that if designers would think about the shop side we could give them a good job at reduced cost. I entirely agree with what Mr. Cole says about the universal nature of machine tools. I am very reluctant ever to buy a machine tool which is very special, and I think the buying of very special machines was a mistake made to a great extent by the motor car industry. Regarding maximum capacity—what I have in mind is this. If you are always working on the maximum capacity that the machine will do, the machine will normally be subjected to a good deal of maintenance cost. Regarding two-years' life. Obviously you could not go on working on that plan for ever, but if the engineering firms in this country would start on this two-years policy they would be astonished by the number of machines that they could replace, which would be paid for in two years.

Mr. Ellerby: Allowance for wear and tear of machine tools. Mr. Wray states this is $7\frac{1}{2}\%$ plus 10% of the $7\frac{1}{2}\%$, which gives us $8\frac{1}{4}\%$. I thought this percentage was never below $12\frac{1}{2}\%$.

Mr. Wray: Regarding the allowance made by the Inland Revenue authorities for wear and tear of machine tools, you will notice I deliberately said: "Had to be agreed by the Inland Revenue authorities." The allowance is not fixed by law, but has

to be agreed upon by the authorities and the firm in question. There are limits much higher than $7\frac{1}{2}\%$—even up to 20%. These have been determined to cover a large number of industries. In each industry there are categories into which different kinds of plant are placed for taxation purposes. If you have any doubt at all, and think you are being overcharged, you can see the Inland Revenue authorities and discuss it with them and come to an agreed figure.

MR. HEY: Mr. Wray remarks that he would be very loath to purchase special machines. I should like to point out that the special machine of to-day is the standard machine of to-morrow. If we look back on our apprenticeship days we will see that this has always been so. Look to-day at the number of different types of machines we have to choose from—all these were special types of machines at one time and they are the standard types of machines of to-day.

MR. WRAY: I think Mr. Cole had in mind a machine for just one special job and which could not very well be used for anything else.

MR. DAVIES: Mr. Wray did not cover the subject of import duties on machines bought outside of England, and if you buy a foreign machine to-day and sell it to-morrow you would show a loss corresponding to the amount of duty paid.

MR. WRAY: If you buy a foreign machine you have to pay import duty. This is a capital charge; for instance, if you buy a machine at £1,000 and you pay £200 import duty on it, that is a capital charge, just as if you bought the machine in England for £1,200.

MR. DAVIES: Yes, but the customer would immediately point out the list price.

MR. WRAY: No, it may be the list price but it is not the total price of the machine. For instance, the same remark was made at a board meeting in Russia. A gentleman said, "Your price is so-and-so. You sell them at that figure, don't you? All right, we will buy them from you at this price plus insurance, etc." And that is the real price and it is a capital charge.

MR. KNIGHT: Is it a fact that any special machine not obtainable in England is allowed into this country duty free?

MR. WRAY: Yes, if it can be proved that the same type of machine is not made in this country.

MR. DRANE (Section President, in the Chair): If the discussion has now finished I would like Mr. Tipple to propose a vote of thanks and Mr. Cole to second it.

MR. TIPPLE: It gives me great pleasure to propose this vote of thanks to Mr. Wray for his very interesting lecture. I have met Mr. Wray on business six years ago, and even in those days when I was attempting to sell him machines he produced his balance sheet and wanted to know how his purchases would fit in. I remember once going to a large railway shop, and before these people can buy

a machine they must produce a balance sheet. The problem was, how could a balance sheet be prepared on a tensile testing machine, and I was told I should be thanked for any suggestions, I said, "You install these machines, then you have an inspector come along to see if they are right. If you keep him waiting he gets annoyed and then he says he will come again tomorrow. Your material is held up, your machine is held up, and you cannot get on with production."

I had another case when I went into a works in Sheffield. The works manager said, " You can come into the shop as I know you are offering me a good machine. If you can show me how this new machine will pay, I will put it up to my directors." I went in. He had a little low building about the size of this room. I saw six machines crawling slowly round. He said, " Your firm sold me these six years ago and we have worked out the depreciation and everything." " They go so slowly," I said, " that we would get you five times the production you show now." "They go so slowly," he said, " that this old man of seventy years of age can look after six of them, and he is so old he gets a pension and we pay him 10s. below the Trade Union rate." So I gave the job up and thought I would leave it till time and providence had done its work.

This is a question of balance sheets and actual experience. We are often asked, what about making machines more and more fool-proof ? I was once asked all sorts of questions about what would happen if a labourer was put to work on a certain machine. I told them that if such and such a lever were pressed, this would happen, and if another lever were pressed, something else would happen. I said, " You have no need to worry, whatever the man does the machine will be all right." I was asked what would happen if a semi-skilled man were put to work the machine, and what when a labourer was put on it. At last I said, " You asked me if it was fool-proof, and I said yes—but if you ask me is it damn-fool proof, no ! "

This question of tolerances. I am certain that we often specify to half a thou., which results in a job having been put on to the grinding machine, because people are under the impression that you cannot do it to a thou. without that extra grinding operation. Give a man five thou. where the job does not not demand any more, and tie up the tolerances where they are really necessary. Machines are primarily not cheap, but if we do estimate what these are going to cost and allow for all incidental charges, such as tool charges, etc., we shall benefit by that because it is only by getting a good sound job that ultimately any firm or any industry can prosper.

I came across a case not so long ago, at a lecture I gave in Manchester, when a gentleman got up and said he had introduced air chucks, which had produced a saving of 80%. I could well believe it, because that was a case where the production time was very small

compared with the chucking time. We keep going round in a circle. One time we have to see that the cutting time is reduced ; now we are getting so that we have to see that the flow of material comes right, and so we go on.

I am sure we have all enjoyed this lecture tonight. It isn't always what a man says but what he gets you to think about later on. Mr. Wray has given us things to think about—slipping clutches, which, if you run them slow enough, do not slip. I have very great pleasure in proposing a hearty vote of thanks to Mr. Wray for his lecture tonight.

Mr. Cole : I have very great pleasure indeed in seconding this vote of thanks. I am sure everyone has enjoyed the evening.

Mr. Wray : I realise that tonight's subject is a rather dry one, but I do think that engineers really ought to learn something about the cost side, and I thank you all for listening to me tonight.

AIRCRAFT PRODUCTION.

Paper presented to the Institution, Manchester Section, by A. G. L. Langfield.

I AM afraid I shall have to give rather more time to design matters than I had originally intended, because the manufacture of the type of aircraft to be described has not yet been launched on a mass production basis and therefore many of the details of the methods of fabrication have not been fully worked out. I shall devote quite as much time to stating what many of the manufacturing problems are, as I shall explain how a number of production difficulties have been solved.

To begin with, it is a fact that the monoplane type of construction is rapidly ousting the biplane type, and the reason for this will be readily appreciated if you consider the front elevation of the modern monoplane in comparison with the front elevation of a biplane. Two things will be noted, firstly there is a great deal more of the latter to be seen than the former, namely the struts and wires interconnecting the wings, and secondly, the undercarriage, which in the case of the monoplane retracts into the wing. These items contribute nothing to the lift of the aircraft but do help to put up the " drag " considerably. Quite apart from dragging these parts through the air there are interference effects between one part and another, for example between the top centre section and the body, causing volumes of turbulent air to travel either with or in the wake of the aircraft, which again has an adverse effect on the speed of the machine. In the case of the monoplane these effects are largely absent. It is, therefore, a faster machine for the same available power. A much better view is another point in the monoplane's favour.

It will be obvious to structural engineers present that the wing arrangement of a biplane should result in a stronger and stiffer structure than the wing of a monoplane, by reason of the fact that the depth of the biplane wing structure is the distance of the wings apart, whereas the depth of the monoplane wing girder cannot be greater than the distance between the upper and lower surfaces of the wing.

Since the strength and stiffness of a girder increases directly with its depth you have at once the reason why biplanes were used in quantity so many years before any extended use was made of

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monoplanes. After years of close study, aircraft structural engineers have overcome the difficulty of providing adequate strength and stiffness in such wing structures and now the monoplane type of wing is being universally adopted. Adequate stiffness and strength are obtained in the monoplane wing by ways to be described, but it is obvious that its thickness is of first importance. This will increase the drag, but this is more than compensated by the saving of the undercarriage drag when retracted into the thicker monoplane wing.

For the sake of simplicity in describing these metal-clad aircraft, we will consider the fuselage first; the reason for this will be apparent later. Consider then the ordinary girder fuselage, composed of scantlings or longerons and the shear members. In the finished state to this load carrying framework is fitted a secondary structure of light formers to which the fabric is attached. That is, there is an internal framework complete in itself and strong enough to resist all air and landing loads and a light framework externally to that for supporting the doped fabric fairing. This fabric and the secondary framework contribute nothing at all to the strength or stiffness of the aeroplane. The fairing also has a real disadvantage inasmuch as the internal strength girder is hidden from view and small damage cannot be seen by external examination.

The modern monocoque fuselage consists simply of a structural shell made up of the longtitudinal members which we call stringers, of flanged channel form, rib members or formers which give shape to the body, the metal covering known as the skin and $^{3}/_{32}$ in. rivets that hold the lot together. These fuselages are made on a jig consisting of a framework of four rails and shear members in form like the internal structure in the ordinary fabric covered fuselage just described. The whole framework is rigidly held at one end, while at the other there is a triangular support which can be swung down to allow the completed fuselage to be drawn off the jigs. The formers are then placed into position, each one being held by eight swivelling clips. The formers have notches cut in them into which the stringers are fitted. The stringers are not secured to the formers in any way—simply resting in the notches. The skin is then laid on this system of stringers and formers and secured with rivets. The shell is then completed, each swivelling clip is swung to one side clear of its former, and the whole body is then slid off the jig.

Now, as to the wings, here the problem is very different. The wings have to resist a greater bending moment than the body and the depth of the wings to resist that greater bending moment is much less than the depth of the body, thus the stresses induced in the wing will be higher than in the body, and a construction

differing from the construction of the body is required to counter these high stresses.

One may here say that the maximum stress induced in the body, reckoning all the skin and formers together as resisting the forces, is in the order of from four to five tons per sq. in. Thus a thin light alloy is well suited as the material of construction. Higher stresses could be induced, but the thickness of the skin is also governed by such questions as handling and resistance to damage.

The complete fuselage for a modern twin-engined machine consists of separate lengths, of which the centre portion probably comprises about 75% of the total. The other two elements are known as the fore and rear end. Both these are detachable. The three portions are joined together by external covering strips.

It is essential to grasp how different this light metal construction is from constructions employed in other branches of engineering —civil engineering for example.

Before the first monocoque fuselage was made a large amount of research work was undertaken. A cylinder was built identical to that used for the manufacture of actual fuselages, in order to ascertain something in regard to the strength of this reinforced shell type of construction. It was subjected to a pure bending couple, that is, there was not shear in addition to the bending. Buckles formed at an early load in the rectangular panels bounded by the stringers and formers—they were elastic and disappeared when the load was removed. This state of affairs continued until one of the stringers collapsed, the attached skin in the region of the broken stringer being permanently deformed. It is extraordinary how much deformation the skin will sustain without permanent set while the stringers are undamaged, such deformation being invariably elastic when the stringers are in the undamaged state. The same remarks apply when the couple is due to torsion, except that in this case the skin may tear before the formers or stringers become permanently damaged. The main conclusions drawn from these two sets of tests were that whereas the spacing of the formers is of small account in the bending test, such spacing is of paramount importance where large torsional forces have to be resisted.

After these experiments elaborate researches were undertaken in an endeavour to obtain some exact knowledge in regard to actual stresses and strains in the stringers and in the skin, together and separately. Strain measurements were taken from 16 points simultaneously when the cylinder was under load. All this work had its uses in regard to structures of simple mathematical form, in indicating what are the fundamental considerations to be taken into account in stressing these reinforced shell constructions, but such theory obtained from this work is at the present stage of

development always checked by actual mechanical tests on the fuselage of the aircraft itself. Discontinuities in the surface, such as doors and windows, may have an adverse affect on the strength and stiffness of the structure and need checking. Such tests include an up load applied through the tail wheel, the whole machine being held by the wing centre section, torsion and sideways bending test, such as is applied to a fuselage when the fin and rudder are brought into action in flight, the load being applied to the top of the fin, the machine being held as before by the centre section.

As already pointed out, the wings present a much greater problem. The loads in the booms can be very high. Here high tensile steel is well suited as the material of construction, since its use will result in the lightest load carrying member, providing the high stresses are really developed. The principle of high stress development is utilised in the design of these wings, inasmuch as the large bending moments are resisted by the spars, the flanges of which are constructed from high tensile steel strip rolled into sections with outwardly extending flat edges, the centrally disposed lip used for the attachment of the web plate and the other edges for the attachment of the skin. This covering of sheet metal is of paramount importance in enabling a state of high stress to be developed in this element of the structure. It must also be clear that the torsional stiffness of the wing is much greater when a structural box is provided through the use of a rigid skin, than would be the case if the wing was covered with fabric. High stresses are induced in the spar booms by making up the section using a number of high tensile steel strip laminae which drop off as the stresses diminish, thus keeping a fair uniformity of stress and a corresponding saving in weight can be readily effected.

The design of the thin spar webs is totally different from that used for the design of thicker webs in, say, bridge girders, for under quite low loads diagonal waves appear and a stress system known as a " tensional diagonal field " forms. The main essential is that the spar booms shall be stiff against bend, so they are stayed apart by means of the web stiffeners which should not be outside the limits one-sixth to one-half the depth of the girder, if the booms are to be adequately stayed against buckling.

The wing shape is obtained by ribs which are secured to the spars and to the skin. The manufacture of these on a mass production basis also presents a problem, since in the modern monoplane with tapered wings no two are the same. Press tools to blank and flange in one operation would cost something in the neighbourhood of £200 each. They are made by hand, the first bend by beating over a template and the second flange on a rapid flanging machine.

The finished wing was tested hydraulically by means of pressure gauges checked by a hydraulic balance, this being a great improve-

ment on the old method of testing which consisted of loading an inverted wing with sandbags until collapse occurred. The load from the sandbags becoming dynamic instead of static it was often not easy in the resultant smash to determine which was the original cause of the failure, whereas the hydraulic load is realised automatically as the structure yields.

The corrugation of strip material into various stiffening shapes is an important part of the construction of these aircraft. This is carried out mostly by rolling mills, but in some cases the strip is drawn on benches.

(*The lecture was illustrated by lantern slides.*)

Discussion.

Lord Sempill (President of the Institution): I am sure you will agree with me that, knowing as you did, that before this paper was given the lecturer had only had a few hours to prepare it, he has really acquitted himself very well indeed. I hope we shall have a long and interesting discussion and we are fortunate in having with us someone to open up the discussion—someone who has had a long and very wide experience in aircraft—Major Barlow, of Fairey Aviation Co. Perhaps some of you do not know that a good many years ago when the testing of aircraft emerged from the mist and become something very highly specialised, the person who got down to the technicalities and evolved schemes and modifications which are in use in this country and other countries where aircraft is made and tested to a high degree of precision, was Major Barlow, who was technically the creator of that organisation.

Major Barlow: My Lord Sempill, President, and Gentlemen: On behalf of the members of the aircraft constructors here, I should like first of all to say now very sorry we were that Mr. Pollard could not be here to-night. He has been a personal friend of mine for many years and we do hope his illness is not serious. At the same time I should like to endorse what Lord Sempill has already said, that he could not have chosen a better deputy. He has put this lecture through to us in a very able way and looking at it from the view of those not connected with aircraft, I can say that you have listened to a very able exposition of the art of constructing aircraft. I notice on the invitation ticket Mr. Pollard's description of the most modern type of aircraft! However, I am going to take exception to that. *We* claim the most modern aircraft. Perhaps we can do something about that later. Bristol has done a tremendous amount of research work, not only on items that are particular to us, i.e., not only for our industry but for the engineer generally, a considerable amount of data, following through tests on light alloy work and so on will be of use to many. Most of us appreciate the work being done by Mr. Pollard and his assistants on structures made from light gauge steels and alloys. There is one point I am going to mention—mass production. I think we ought really to get down to the fact that there never will be mass production in aircraft.

You will notice that there is a tremendous lot of mechanical tests. To those not connected with the aircraft industry I do feel it should be explained that these are purely in the nature of technical general work, necessary for production. One must say, with all due respect to officialdom, there will certainly have to be a big change

in many ways to get down to, not mass production but real production which could cope with their requirements during this expansion period—and certainly during war time.

Two points arise. First of all, the number of materials. There are too many specifications. We deal with some hundreds. If we are going to get down to real production we have got to bring that list not only down in numbers but materials, which can be got easily during this period. These high grade alloys and various other combinations of light alloys, all want to be brought down to a more standardised basis, so that we can order our materials and get them in reasonable time. The same thing applies to steels and various other parts of the aircraft.

MR. CHADWICK: First of all, may I thank the Institution for their kindness in sending us along some invitations to attend this interesting and instructive lecture. Secondly, I should like to congratulate the lecturer on his paper and the way he has delivered it. As Major Barlow said, it is quite obvious the Bristol Aeroplane Co. have done a great deal of research work in connection with the development in construction of aircraft and it is very kind indeed of them to tell us something about it. I am sure that the aircraft industry at the present time is earnestly collecting all the information it can in this direction and I think it will be extremely helpful if we all put forward the information we get from our various tests.

There are one or two questions I should like to ask the lecturer, if I may. I should like to know what are the usual thicknesses of material which the Bristol Aeroplane Co. are using for the covering of their fuselage and wings? What range of gauges they employ? Another question is, it would be very interesting to know whether they arrange the pitch of the stringers entirely from their test specimens or whether the pitch of the stringers is decided upon from practical manufacturing considerations. I notice the lecturer said in the fuselage the stringer-skin combination developed 5 to 6 tons per square inch in compression. We have on test specimens developing higher stresses than that and I am rather surprised that they have worked down to so low a stress as 5 to 6 tons per square inch. This raises the point in my mind whether the disposition of the stringers was arranged for manufacturing.

Another point I should be very interested to know, personally is, whether when they design their fuselage to be satisfactory from the strength point of view and whether it automatically takes care of the torsional loading. Our own tests appear to indicate that to be the case. Perhaps the lecturer would tell us something about the principle the Bristol Aeroplane Co. employ in designing the frames around the necessary opening in the fuselage for doors, windows, etc., I should also like to know whether in these spar structures as shown on the screen the basic section of the spar

is carried right through the wing, also is the doorway stiffened up by additional laminations.

MR. LANGFIELD: I should like to thank Lord Sempill and Major Barlow for their kind words. I am afraid I am a very poor substitute.

Regarding the question of gauges. We have never used in actual aircraft a gauge thinner than 24. We do use 24 sometimes underneath the wing, but do not use it at all in the fuselage. Both for the covering of the wing and covering of the fuselage itself we use 22 gauge. The formers are also of 22 gauge material.

Regarding pitch of stringers, actually we get out pitch from design considerations and from manufacturing considerations. We go into both sides of it. The design people say they want so many. The production engineer finds it an awkward job or he has his own ideas about it; he puts it up to the design staff and between the two they come to some sort of agreement as far as pitch is concerned. The original design is sometimes modified to suit production where this is possible.

The question of development of 5 to 6 tons. I quite appreciate the fact that you can design for a much higher stress in the fuselage. However, the covering of the fuselage was fixed at 22 gauge, this being considered the minimum practical thickness of the skin or section. We came to the conclusion that 22 gauge was fairly safe from handling considerations. We would of course use a thicker skin and get a higher stress in consequence, or we could put the stringers closer together and make them heavier or more involved in shape and more difficult to assemble. Any or all of these things would give us a higher stress. The question is, would a higher stress be of any advantage in this connection?

As to the question regarding the torsional stiffness of the fuselage, this certainly is inherent in the design of the fuselage. We have carried out tests on completed fuselages and we have always found them well within the specified requirements. The theoretical side of this work has now developed so far that both strength and torsional stiffness can be estimated with equal facility.

As regards holes, as you will have noticed from the views showing the production of the machine, there are a lot of them—doors, cockpits, and so on. We reinforce these locally with what would amount to a patch on the inside, and for the doors we make a wooden framework built up of a number of laminations. This is held between Z section formers and reinforced with the patch. We had to cut an enormous hole in the side of the Tranport Bomber to accommodate wide tanks and all sorts of things inside. As shown in the slide, a large panel was made a tight fit with dovetail blocks in order to transmit some of the stresses. This could be removed without seriously affecting the torsional stiffness of the fuselage.

Re the section of the booms. I do not quite follow the point. We drop off the laminae towards the wing tip, but retain the basic section. So of course the section does actually vary. We have as many as twelve laminations to be dropped off one by one in order that the stress might be kept up in spite of the decreasing loads in the spar outwards.

Mr. Taylor : It has been an interesting lecture. There is one little point on which I should like information. In all their tests and diagrams of construction they shew the open type of stringers. I should like to know if they have found any advantage in using the closed stringer as against the open type of stringer for manufacturing considerations. As to spars, how do you get rid of the twist that must occur ? Do I take it one of the angle laminations is twisted throughout its length ? One or two slides showed under certain loadings rather bad wrinkling.

Mr. Langfield : Regarding the question on open stringers, I said that on the first machine made (which by the way was the first low wing monoplane to be adopted by the Air Force) we had the stringer round the other way. The figures are actually only 7% down on the closed stringers. There is much less riveting in the case of the open stringer and from other considerations mentioned such as ease of attachment of internal fittings on the open stringer, etc., we consider the 7% sacrifice in strength well worth while, having regard to the fact that there is still an enormous reserve of strength.

Regarding the question of twist on laminations as they go outwards towards the wing tip. I do not know exactly what the variation in the angle is towards the tip—I believe it is only a few degrees in the worst case—four or five. However, we do actually bend these—just to straighten into position by hand. Once the cornice is in place that holds the angle to the correct contour. As to the crinkling, this is inevitable before collapse on test, but it does not happen when a machine is flying except elastically in the most severe aerobatics.

Mr. A. Vines : In this stressed wing, where they want torsional stiffness, do they ever have detachable panels ? How do they ensure quick detachability for maintenance, etc. ? What arrangements are made for fixing panels—is this through the use of an enormous number of screws ?

Mr. Langfield : It is quite true that we do have to cut large holes in wings for tanks, bombs, etc. Torsional stiffness is obtained when detachable panels are used through the employment of large numbers of screws as the questioner suggests. It is quite obvious that by putting a great hole in the bottom you must reduce torsional stiffness a little but our method of fixing movable panels adequately restores this very necessary quality.

MR. HOOD: Quite a number of us are not actually in the aeroplane construction business, but a lot of it is very common to the industries we are in. It is very interesting to note the introduction of stainless steel rivets. I notice there is not a great deal of welding shown in aeroplane production. I am interested to know why development in this direction is not mentioned. How does he know after these wings have been suitably covered that something is not taking place due to stresses and strains, etc., that those rivets are not a hidden danger? I should like to know what sort of material is used, the difference in strength, support, and structure in holding the engines in the plane.

MR. LANGFIELD: On the question of welding, we do weld small fittings and the like in Bristol. However, we do not make a welded structure, that is, the safety of our aircraft does not depend on welding. The examination of rivets is a point I meant to bring out in the lecture. In the event of a heavy landing or crash in the old type of fuselage where you had everything hidden away inside a fabric bag and where there was an enormous conglomeration of sub-structure as well as main structure, it was quite a business to discover how much damage had been done. But in the case of a monocoque you can see the condition of the structure as a whole and not only the rivets from the outside. This is a most important matter from the view point of safety.

MR. OWEN: I was interested in one of the slides showing the assembly shops. I would like to ask about a number of pendant lights hanging from the ceiling 10, 12, or 15 ft. Are there occasions when heavy weights need lifting from one shop to another—where the pendants are you cannot use overhead cranes?

MR. LANGFIELD: The lifting of heavy weights is not one of our problems. In aircraft we do not deal with heavy weights and the fuselage I showed you, being made on jigs, is quite easily picked up by two or three men and a boy and they handle it quite simply. Of course we have no overhead crane at all at the factory and no real heavy weights to deal with. It is a matter of proper progressing. The aircraft is soon on its wheels. 30 cwt. portable cranes are all we find necessary for weight lifting.

MR. METTAM: I should like to congratulate the lecturer on the way he has put the subject before us. I have known Mr. Pollard for many years and he has a tremendous enthusiasm for the work on which he is engaged. With regard to the fuselage in torsion, the spacing of the stringer was not particularly important, the spacing of the hoops being the main consideration. A test of a cylinder in torsion as shown on a slide developed 45°. It appeared from another picture of a fuselage in torsion to be 60°. Would the lecturer indicate what is the best rectangular shape of the panels that are left between the hoops and the stringer arrangement. With

regard to the question of Alclad, I would like to pooint out a fact well-known to members of the aircraft industry, that the putting of pure aluminium on the outside of the duralumin is to prevent corrosion, and it is performing that object.

MR. LANGFIELD : I do not feel qualified to give an answer as to best "free panel" shape. Owing to the diversity of loadings to which the structure of an aircraft is subjected, I imagine that there is no general answer to the question "What is the best shape of panel ?"

A VISITOR : Someone was telling me the other day (I may have been having my leg pulled) that the latest practice now in rivets was to have something after the style of an oval nail put in streamlined and depend on the oval shape to get a streamline shape on the rivet head.

MR. LANGFIELD : With regard to the question of rivets, I am afraid the gentleman *was* having his leg pulled. I have not as yet heard about a definitely streamlined rivet. We do use a special rivet in Bristol with a shallow head and rather long. Regarding the question of Alclad, the sheeting is made by rolling ingots of hot duralumin with about 1 ft. × 1½ ft. sheets of aluminium on either side, ¼ in. thick. The composite slab starts life like a sandwich, the cold thin slabs of aluminium are put in a mould and the molten dural is poured between these slabs. Just the inner surface of the aluminium melts and binds with the duralumin. Then this slab, some 5 in. thick, is passed through an elaborate rolling mill and is reduced to the required thickness, the ultimate thickness of the aluminium corrosion proofing surface being some five-thousandths of an inch for the Alclad covering I have described to-night.

MR. HOOD : I understand that description of rolling aluminium and duralumin together but experience (bitter experience) has shown me that pure aluminium definitely does corrode. We have been having some very large experiments recently trying to get pumps that have been made out of stainless steel, which have corroded under certain tests, for fire engines, and we find no particular supplier will give any guarantee. Anodyzing has come along, which we fled to as a solution of this and I had some tests made and put some parts outside with no covering on at all and corrosion has come in already—unless there is some peculiar marking creeping through. How do you look for fractures and what we term splitting ? For instance, I notice a number of supports, gussets, struts, etc. We have got them in all metal buses. Outwardly they look good, but when you look inside you have a revelation —rust and corrosion. Do you make special tests of your steel structures to see there is no flaking or chance of internal fracture that you cannot see ? What practice have you ?

Mr. Langfield: With regard to Alclad, I have always heard it was very satisfactory from the point of view of corrosion as we use it in aircraft. However, as a small point of interest, before joining two pieces of Alclad together we always spray with varnish. We similarly spray the outside of the whole fuselage with varnish as well and follow it up with a spray to give a silvery look and take away the shininess.

Regarding the question of flaws, those who have had no experience in the aircraft industry do not realise the enormous number of inspection tests that are taken from the time the material leaves the manufacturers until it reaches the finished aeroplane—rigorously inspected—heat treatment very carefully watched. Each finished part is inspected and stamped with an inspector's stamp and the whole sub-assembly is again checked by another inspector. The fuselage itself or any other sub-assembly is again inspected, put into stores and then the complete assembly is inspected by the ground inspector before it flies. Unless you are connected with the trade, the ordinary mechanical engineer does not realise how much money we have to spend on inspection. We know something of 'bus construction. That and aircraft construction are as different as chalk from cheese. I could very well have spent the whole evening lecturing on corrosion processes as applied to aircraft. We learned years ago that corrosion and fatigue cracking largely go together, therefore we eliminate corrosion; by keeping working stresses low we have practically eliminated the possibility of fatigue cracks from high alternating stress causes.

A Visitor: You illustrated two tests on aeronautical structure. One was powered by hydraulic jacks, the other was somewhat more clumsy, in which you placed weights corresponding to the stresses to which the structure was subjected in the air, and you said that when collapse occurred under the old method of testing you could not ascertain what had collapsed first, because of the wreck produced. In the new way you presumably could. Do you find any evidence of tearing of the metal where rivets were used?

Mr. Langfield: The structure collapses at its weakest point—it may be rivets shearing, metal tearing in tension, struts bowing, etc. In the new hydraulic method of test the load is automatically relieved at the first sign of collapse, repair made and the test proceeded with but in the old "dead-weight" method, after the first failure, collapse was simply intensified and spread with great rapidity, often so rapidly that the first failure was not discernible.

A Member: What is the effect of the temperature variations you get on the aluminium and duralumin due to the coefficiency of expansion where you get a plane in the tropics and ice forming on the wings? Are there not undue stresses set up? Are they calculated for?

Mr. Langfield : If you have a structure made entirely of one material it all expands the same. It would appear that there might be some sort of problem where you are riveting H.T. steel strips and duralumin where there is a definite difference in coefficiency of expansion between two materials. However, we have as yet experienced no trouble, our experiments being limited to the use of a refrigerator ; different materials riveted together under that condition shows no cause for alarm. As to heat, we are actually sending one of our machines to Egypt and I do not think we are anticipating trouble. If we do get it, we shall find some method of solving it.

Mr. Leslie : Following Mr. Hood's remarks, it would be interesting to production engineers to know whether you do carry out any welding of the structure or whether you have as yet no confidence in welding, or if it is a question of oxidisation during welding. I rather gather you do a fair amount of welding. It would be interesting to have some further knowledge on this from someone in the audience or the lecturer.

Mr. Langfield : I cannot say much more than I did a few minutes ago, namely, that we do not use welded structures but we do use welded fittings. Successful structures are, however, built by others employing this method solely. Perhaps someone from Messrs. A. V. Roe & Company could give you some further information.

Mr. Chadwick : As a matter of fact A. V. Roe do fabricate a considerable number of their frames by the oxy-acetylene welding process. Some years ago there was a great prejudice in this country against the use of welding. It was not considered reliable and we had difficulty in convincing the Air Ministry that a reliable welding could be produced. The trouble was, of course, with the early welded structures—unsuitable steel being employed and there was not sufficient knowledge of the problem connected with the welding assembly of these very light and thin welding structures, but we have now had a number of years experience with welded structures and I am very glad to say it has proved to be extremely reliable and easy to manufacture and repair.

Lord Sempill : I would like to say how pleased I am to be here with the Manchester Section because it is a visit I have been looking forward to for some time. Throughout the Institution—in London and elsewhere—we always look to the Manchester Section with great confidence that it will be a source of strength to our Institution.

In regard to the lecture, it strikes me as particularly important because whatever the position in the past may have been, we are to day in the position of having to acknowledge publicly that the country's defences, surveyed from every point, are far below what

they should be. Aircraft plays a very important part in our armament programme, and, therefore, lectures of this kind, fixing attention on the methods for producing aircraft more rapidly and effectively, are very important in order to get that knowledge spread about as widely as possible.

On the other side, namely, the development of commercial aviation —we are no doubt behind in the development of the larger type of aircraft for commercial purposes, due largely to the fact that there has been no acknowledgment, as in some other countries, that the organisation of air services is a matter of vital importance to the future of our Imperial communications.

Obviously, the main solution is one of production not only in aircraft but in all other branches. There is no question that our Institution has a very great work in front of it which I am sure it will perform with increasing energy in all parts of the country.

We have had a very interesting lecture and an interesting discussion on some of the aspects of the production of metal aircraft. I think it will probably interest some of you to look on another side of commercial aircraft production, particularly to-night, because an hour or so ago LZ 129 proceeded to America. Now this is a structure which is similar in general dimensions to the size of the *Queen Mary*, and when that structure was designed, now about six years ago, the weight of the structure itself was calculated from the design data then available, and when the ship was weighed off a little less than a year ago, the previous calculations and the actual weight differed hardly at all. That gives you some idea of what can be done in the realms of another side of aircraft production by the accuracy of the designers and engineers.

In regard to the question of corrosion, that, of course, depends on the type of craft to be used, whether land or sea-going machines. In the latter case, the situation is very difficult and a very serious one, but, taking a large structure, such as the sister ship of the L 27 Graf Zeppelin, now in about the seventh year of her service—no single part of that structure has been replaced due to corrosion defects. That is an airship built long before Alclad was known, protected by a certain type of protective varnish, which has been sufficiently effective in avoiding difficulties of corrosion.

GRINDING WHEELS FOR THE SHEFFIELD TRADES.

Paper presented to the Institution, Sheffield Section, by A. W. Lee.

THE title of this paper as chosen by your Committee covers such a wide field that it is impossible to do justice to all aspects of it in the time at our disposal. The use of natural stones for sharpening and polishing implements and tools of various kinds, dates from very early times. Those engaged in the older Sheffield trades are very familiar with the advantages and disadvantages of the use of natural sandstone as a means of shaping tools and articles for which Sheffield has been famous for generations.

The times are rapidly changing and while it will later be necessary to refer to some of the older processes and the wheels used, this paper will deal mainly with modern abrasives and the newer applications of modern grinding wheels to local industries.

The sandstone, both in wheel and segment form, was at one time predominant in Sheffield trades but changed times needed changed methods in order to cope with modern demands. The natural abrasives could not cope with all the grinding tasks set up by the delicate requirements of modern industry as it is developed increasingly hard and tough materials and advanced to new standards of precision.

The modern grinding wheel is a scientifically developed cutting tool, applicable not only to the hardest and roughest work, but also to operations requiring the greatest degree of precision. Every step of manufacture is controlled by the laboratories, aided by research departments, for chemical, physical, and mechanical study of the raw materials, methods of manufacture, and the resulting products. As an instance, without the aid of modern grinding wheels and machines, the motor industry would be unable to shape interchangeable parts to close measurements from tough stock at low cost.

Before proceeding to the use of the grinding wheels themselves, it might be of assistance to some to first describe how the various parts of a modern wheel are dealt with. In almost all grinding wheel problems, the solution to a difficulty is to be found in the neglect or omission to observe some elementary principle. Those

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whose duty it is to correct grinding wheel faults, or who have to make selections of wheels for particular operations, have always to bear in mind the type of grain to use, the type of bond necessary, the hardness of the bond, and the type of operation to be performed. The condition of the machine, sometimes the methods of the operator, and many similar matters must come under review in order that maximum production at the cheapest rate may be obtained.

Grain.

Cutting efficiency in a grinding wheel is dependent upon the quality of grain used in its construction. The bond and its hardness or tenacity are important. So is the structure or the spacing of the grains in the wheel, but that which matters most, is in having good quality grain incorporated, a grain of which the characteristics, chemical, physical, and abrasive, are constant and known.

In this natural sandstone the cutting element is quartz grain. This is not as hard as natural emery or Corundum, which were the abrasive materials used in the early experiments in artificial wheel manufacture. Emery and Corundum proved to be very unsuitable and variable in composition and it became necessary to obtain better abrasive materials in order that the grinding wheel might become an active producer in modern industry.

All emery contains a considerable proportion of non-cutting elements composed of amorphous alumina, silica, ironoxide, and other metallic oxides; in fact, it is the ironoxide which gives emery its dark colour and which enables it to be easily distinguished from Corundum, which is of a lighter shade. Corundum may be shortly described as natural emery with some of the impurities left out, especially the ironoxide. Ironoxide is an objectionable impurity in abrasive grain.

On steel operation and upon all high tensile materials, the cutting element necessary in the abrasive grain is oxide of aluminium, which is present in both emery and Corundum. Some qualities of Corundum have a good proportion of aluminium oxide in their composition, but emery does not show up as well in this respect.

Nature having failed to supply an abrasive sufficiently good to satisfy modern requirements, scientists entered the field and made possible a range of abrasives which are rich in practically pure aluminium oxide. These abrasives are constant and reliable and under definite control during manufacture.

Scientists also gave to industry another abrasive which has no counterpart in nature—carbide of silicon.

The Abrasive Si. C. is produced in a resistance type of electric furnace, from a mixture of sand and metallurgical coke with salt and sawdust present to facilitate the reaction.

The type of furnace used is a large brick box about 20 ft. or more

in length. Through the centre of the mass of coke and sand mixture is placed an electrical conductor. The current passing through the carbon conductor generates heat and brings about the action between the sand and coke. When a furnace is operating, flames can be observed all around this open brickwork structure, caused by carbon monoxide gas liberated by the chemical reaction which takes place in the charge, escaping through the furnace walls, where it burns. The reason for adding sawdust to the mixture is now evident, for, when it burns off it leaves a porous body, thereby allowing a means of exit for the carbon monoxide gas and prevents an explosion within the pig. At the completion of the run, the product consists essentially of carbide of silicon in the solid crystalline form, surrounded by partially or entirely unconverted raw material and containing as a core carbon from the electrical conductor. When this pig has cooled sufficiently, it is split open with crowbars and the pure Si. C. crystals separated from the unconverted products.

A Crystolon pig which has been partially stripped shows the different crystalline formations, the crystal zone near the centre of the shell and the dense zone near the electrode. The hollow centre is due to the burning out of the carbon layer laid to act as a conductor at the beginning of the run. The outer surface of the shell has a high percentage of unconverted material which has to be stripped before crushing the ore. The unconverted material is crushed and goes into the next furnace run. If the temperature was allowed to go too high, the Crystolon would be converted into graphite. On the other hand, if the temperature was too low, the silica and coke would not combine to give silicon carbide.

I have here a sample of this Si.C. as it comes from the pig. The quality and crystal structure are, of course, entirely dependent upon the choice of raw materials and on the accuracy of the control and operation of the furnace. The furnace is operated at the temperature close to 4000°F. Lower temperatures would not give the desired reaction between the raw materials and higher temperature would decompose the Si.C. to form graphite.

Crystalline Si.C. Until the invention of Norbide (Boron Carbide) was next to the diamond in hardness. It is comparatively brittle, however, and is used mostly for grinding metals of low tensile strength, such as cast iron and for grinding hard, brittle or rocklike materials, such as marble and granite. The degree of variation possible in its characteristics is rather small. It has a specific gravity of 3.20 and dissociates at 2250°C.

Fused Aluminium Oxide.

Fused aluminium oxide is produced from the impure mineral Bauxite which occurs in abundance in many parts of the world, near the surface of the earth. It consists of hydrated aluminium

oxide Al_2O_3, $2H_2O$ or Al_2O_3, H_2O with varying quantities of such impurities as silica, iron oxide, titanium oxide and small quantities of other minerals. In America large deposits of bauxite are being mined at Arkansas, this district being the source of our raw materials.

The bauxite is dried and powdered. It is mixed with the proper amount of powdered carbon so that in the furnace fusion, the major part of the impurities will be reduced to metals, thereby purifying the final product. The furnace consists of a cylindrical metal shell set on a carbon bottom. The carbon electrodes are suspended from above and a heat of approximately 3668°F. is produced by electric arcs playing between them and the surface of the melt. The outside of the shell is cooled by a stream of water which serves to solidify a thin layer against the shell, thus forming a container for the remainder of the molten mass. The mixture is fed in at intervals by hand and the electrodes are slowly raised as the charge melts down. The reduced metals separate out by gravity as a layer below the liquid alumina. After the electrodes are withdrawn, nearly a week is required for the pig to cool down. When the pigs are sufficiently cool, the workmen break them up with sledge hammers and crowbars. It is only by following the cooling cracks that these pigs are successfully broken up.

In Alundum grain E.1 shape, long weak slivery grains are eliminated. The grain shape is of the blocky type of uniform size, and while the special milling process produces this strong type of grain, the sharp cutting edges are maintained. This is the shape of grain used extensively in regular Alundum wheels.

No. 38 Alundum.

To produce a high purity aluminous abrasive, the furnace operation is identical with that we have just described. The raw material, however, is almost pure aluminium oxide prepared from the bauxite by the Bayer purification process. No carbon is added to this mixture.

Properties of Alundum.

The physical properties of the fused alumina abrasive are quite different from those of the carbide of silicon abrasive. Fused alumina is intrinsically tougher which makes it much more suitable for grinding steel and other tough materials of high tensile strength. It has a specific gravity of 3.95 and of 2050°C. melting point.

In No 38 Alundum a porous crystalline structure has been developed. This is brought about by exertion of vapour pressure from soda present during the solidification of the fusion from the electric furnace. In all cases, of course, the lump abrasive has to be crushed, washed, iron removed, and then carefully screened to definite grain sizes before being used or made into grinding wheels.

Norbide.

Norbide is the registered trade name for products made of Boron Carbide, an entirely new material recently developed. It is the hardest material produced by man for commercial use and is exceeded in hardness only by the diamond.

It is used crushed to a powder for lapping work, previously only possible with diamond dust or moulded at a temperature of 5000°F. and a pressure of 2000 lb. per square inch into required shapes, which resist wear to an extreme degree.

Norbide abrasive is finding an extensive use in the lapping of cemented tungsten and tantalum tools and dies and being approximately 100 times cheaper, the diamond powder does not have to be used so sparingly or carefully. Other applications now being tried are moulded contact points for micrometers and gauges.

It is difficult to explain the differences in hardness of various types of abrasives, but an interesting table has been prepared which gives a comparison, carefully compiled by the Research Staff, between the hardness of abrasive grains and of modern metallic alloys. In 1820, a Mr. Moh gave some attention to the hardness of natural minerals and compiled a chart or system, the difference in hardness between the various materials being determined by the fact that any member in the series will scratch any of the preceding numbers. The lowest numbers of the Moh scale are not of interest at the moment but the higher numbers now illustrated show comparisons between the hardness of alundum and crystolon grains with some of the modern hard alloys.

As a short guide to ensure the use of the correct type of grain, the following may be given :—

Alundum, or aluminous oxide, for use on materials of high tensile strength ;

Crystolon, or silicon carbide, for use on materials of low tensile strength ;

38 material for steel surfacing operations and for tool room work upon hardened and alloy steels.

The points concerning abrasive grain have been stressed because the cutting efficiency of a grinding wheel cannot be any better than the quality of the abrasive grain of which it is composed.

Characteristics of Wheel as determined by its Manufacture :

The Abrasive.

The method of manufacture of grinding wheels, the abrasive materials used and the nature of the bond, result in giving to the different types of wheels certain general characteristics as regards adaptation to work.

The silicon carbide (Crystolon) abrasive differs materially from the aluminous abrasives (Alundum). The grains of the former are

intrinsically harder but are also more brittle, due to the structure ; the grains of the latter while not so hard, are tougher, and do not break apart so easily, and are thus able to withstand a greater stress. Alundum abrasives in their manufacture also admit of a certain range of toughness due to variations in size of crystals.

On account of the difference in physical characteristics of the two abrasives, a general rule has been established, namely that Alundum abrasives are generally used for grinding materials of high tensile strength, and Crystolon abrasive for those of low tensile strength. While tensile strength alone is not the criterion, inasmuch as hardness and ductility influence the selection, experience has shown that in general, the Alundum abrasives are particularly adapted for the grinding materials of high tensile strength.

It is impossible to set a fixed tensile strength as representing the dividing line between the use of the two abrasives, but 50,000 lbs. per sq. in. may be used. For metals of this strength or over, preferably an Alundum abrasive should be selected.

There are various brands of Alundum abrasives, and wheels made of these abrasives are trade-marked, " Alundum," " 19 Alundum," and " 38 Alundum." The difference is mainly one of " temper," the first mentioned brand being the toughest. " Alundum " abrasive is particularly well adapted for heavy duty snagging operations and for severe precision grinding operations where heavy pressures are exerted. " 38 Alundum " abrasive on the other hand is best suited for the lightest kinds of grinding such as internal and surface grinding and tool and cutter work. "19 Alundum" material is an intermediate abrasive and is well adapted for grinding almost every type of high tensile strength material except where extreme conditions exist.

For metals of low tensile strength, such as cast and chilled iron, nonferrous metals such as copper, aluminium, zinc, tin, and their alloys, and for most non-metallic substances such as wood, rubber, celluloid, pearl, marble, and stone, Crystolon abrasive is in general preferable.

Bonding abrasive grain to form grinding wheels.

Various bonds are used to hold abrasive grain together in a grinding wheel, and the resulting wheels have different properties used for different purposes. Vitrified : Most common, consists of mixture of clays and feldspar. The wheels are fired in ceramic kilns to mature the bond to a glass. Silicate bonds : Essentially composed of sodium silicate, zinc oxide, and fillers. Shellac, hard rubber and synthetic resins such as bakelite constitute the organic bonds, commonly employed.

The grinding wheel which operated best on a particular job is the one which breaks down just enough to keep it sharp. To attain this

result for different grinding operations requires that the abrasive grain be bonded together with various degrees of strength in different wheels. Ordinarily this is accomplished by using different amounts of bond relative to the amount of abrasive grain, giving products which have different " grinding grade " or " grinding hardness."

Characteristics Determined by the Bond.

In addition to abrasive characteristics, the selection is also affected by the nature of the bond, which is the material used to hold the abrasive grains together. The kind and amount of bond used impart distinctive characteristics to the wheel, as indicated in its grade.

Vitrified Bonded Wheels.

The vitrified bonded wheels are standard for most grinding operations, the other types being used only when special conditions are involved. The vitrified process produces wheels of exceedingly strong bond and of a wide range of grades. These qualities, combined with their open, porous structure, adapt them for nearly all classes of grinding work. Approximately 80% of the wheels made are of this type.

Silicate Bonded Wheels.

The firmness with which the abrasive is held by the bond in these wheels is not as great as in the vitrified wheels. Silicate wheels, therefore, are said to have a milder or less harsh grinding action and are especially adapted to that class of work requiring a delicate edge, such as edged tools and cutlery. The cutting action of silicate wheels is similar to that of the natural grindstone. They should not in general be used for rough grinding nor for cylindrical grinding. It is commercially practicable to make them in sizes larger than 36 in. in diameter and the process of manufacture is shorter than that of the vitrified process, allowing quicker delivery in an emergency.

Shellac Bonded Wheels.

Shellac bonded wheels are capable of producing a high degree of finish, and very thin wheels can be made by this process. The elasticity or non-rigidity of the bond is an especially desirable quality in some classes of work, notably in saw sharpening and in the grinding of granite and marble. Shellac wheels are used for the finishing of chilled iron, cast iron, and steel rolls, for the final finishing of hardened steel cams, and in some cases for the grinding of aluminium pistons. These wheels are also used in place of hack saws in cutting-off operations.

Bakelite Bonded Wheels.

Bakelite as a bond adapts itself to the manufacture of certain types of grinding wheels. The exact scope or field of application for

bakelite wheels cannot, however, be definitely defined. It is known that for certain " cutting-off " operations in particular, bakelite bonded wheels excel. Although this bond is of the nature of shellac and rubber bonds, it probably will never replace either of them, but will be used supplementary to them. Bakelite wheels are also used for high speed fettling work.

Rubber Bonded Wheels.

These are used when the nature of the work requires a thin wheel of great strength, as in the grinding of grooves. Thick rubber wheels are also used for grinding of malleable iron and steel castings. They are operated at a speed considerably higher than that employed for vitrified wheels.

Grain and Grade.

Grinding wheels are made in a variety of grains and grades so that the most efficient wheel can be provided for all conditions. The machining of various shapes of work and different kinds of metal requires different cutting edges when grinding, just as would be necessary when turning. A great number of different grain and grade combinations are therefore necessary in order to provide wheels to meet all requirements.

Grain Size.

By grain size is meant the size of the cutting particles ; that is, the abrasive used in making the wheel.

Grain Sizes of Abrasives.

Very Coarse	Coarse	Medium	Fine	Very fine	Flour sizes
8	12	30	70	150	280
10	14	36	80	180	320
	16	46	90	200	400
	20	60	100	240	500
	24		120		600

No. 220 is a standard " Crystolon " grain size.

The abrasive grain used in wheel manufacture is sized through carefully made screens and the finer " flours " are prepared by hydraulic classification.

The numbers used to designate grain size refer to the meshes per linear inch in the various screens over which the crushed abrasive is passed. For example, No. 24 grain is that which passes a screen having 24 meshes or apertures per linear inch or 576 apertures per square inch, and is retained on a screen having 30 meshes or more per linear inch. No. 30 grain is that which passes a 30 mesh screen and is retained on a 36 mesh or finer screen.

Grade—A Range Between Limits.

Grade is a term used to denote the hardness of a wheel. It actually represents a measure of the strength of the bond or the cohesive force exercised by the bond to retain the grain in the wheel. It is not used to express the hardness of the abrasive material itself. Hardness of the abrasive material and hardness of the grinding wheel are two distinctly different things. A grinding wheel may be made of a very hard abrasive and still be a very soft wheel.

Neither is "grade" an exact value. It is a range between limits and all wheels which come within the range as designated by a particular letter or number, are one grade and carry the same grade letter. As an example, grade "L" does not represent an exact value but a range between two limits. It will thus be seen that a wheel marked "L" may be almost soft enough to be designated "K" or may be almost hard enough to be designated "M" and still if within the limits it must be graded "L." The Norton method for designating grades of vitrified and silicate wheels employs the letters of the alphabet from F to Z, F being the softest wheel manufactured and Z the hardest.

Grinding Wheel Markings.

Every wheel is plainly marked with its abrasives, grain, and grade. When the shape permits, blotters are placed on both sides of each wheel. These blotters are plainly marked to indicate the type of abrasive which is used in the wheel manufacture and in many cases the size and specification of the wheel. The grain and grade is marked on one side or in the bushing of each wheel. For example, the marking "46K" means that the wheel is of grain size 46 and of grade K. Reference to the trade-mark on the blotter will indicate whether the abrasive is "Alundum" or "Crystolon" material.

If the wheels are "38 Alundum" or "19 Alundum" brand the numerals "38" or "19" are prefixed to the grain and grade designation. For instance, "3880-J" means that the wheel is made of "38 Alundum" abrasive, of grain size 80, and is grade J in hardness. Likewise, "1980-J" indicates that it is "19 Alundum," grain size 80, and grade J. In addition to this, information tags giving complete specifications are attached to at least one wheel of each lot in a shipment. These tags give the Norton order number, size, shape, grain, and grade. If the process is other than vitrified, this is also given. The trade-mark printed on the tag also indicates which abrasive has been used.

Grinding wheels are sometimes made of a combination of grains and are designated as, for example, 24 combination. A combination wheel with a mixture of fine, coarse, and medium grain sizes has a different cutting action from a straight-grained wheel and is

desirable for certain operations, particularly cylindrical grinding. Such wheels are designated by 24C as 24C-K.

Controlled Structure and " B " Bond.

Controlled structure is a principle of manufacture wherein a definite volume of abrasive and volume of bond are measured into the wheel when it is moulded. Not only is the volume " per cent." of abrasive controlled but the volume "per cent." of bond as well For convenience in specifying definite volumes of abrasive, numbers have been arbitrarily assigned to represent different structural conditions. The normal range of structure numbers varies from 0 to 12, and it should be remembered that the lower numbers represent the higher abrasive contents (denser wheels).

For a given grit size, structure, and grade, our manufacturing specifications required a definite volume per cent of bond must be present in the wheel to obtain the desired bonding strength indicated by the grade letter. Thus, by designating both a structure number and a grade letter, the volume per cent. of abrasive and bond are indicated.

For example	3846 K5B grit size	Character of bond.
Kind of Abrasive	Bonding strength or Vol. % of bond	Volume % Abrasive

To meet the customer's exact requirements as many of the factors given may be altered as are necessary.

Formerly it was an established practice to make grinding wheels to samples, but to-day controlled structure grinding wheels are made to exact specifications. It is a long step toward making grinding wheels to specifications and much in advance from the older and still common practice of making and checking grinding wheels to standards. I do not wish to infer that previous to the development of controlled structure that wheel structure lacked control, this would be incorrect, because manufacturers have always controlled their products by the best available means, It is true, however, that the form of control has been limited and not entirely satisfactory.

All grinding wheels are composed of three constituents, (1) abrasive, (2) bond which holds the abrasive grains together, and (3) pores. Regardless of the method of forming the wheel, these three constituents are present. By changing the volume relationship of these three constituents, the grinding characteristics are altered. Formerly this alteration was usually brought about by employing

either the puddled process or by moulding under pressure. The constituents of the wheels were considered entirely on the basis of weight and the fired volume relationship was governed by control over the manufacture and selection of raw materials, mixing and so forth. The resulting product was inspected for bonding strength or grade by comparison with a sample wheel. If, in the opinion of the inspector, it compared favourably with the sample, it was passed. Although having a definite volume relationship of abrasive, bond, and pores, this was not known. Very general terms were used to judge this volume relationship, such as openness of structure, uniformity of structure and density of structure. Norton controlled structure principle of manufacture was introduced to substantially eliminate variations in the volume relationship of the wheel constituents.

To-day instead of merely proportioning the materials according to weight and forming the wheel, a definite volume relationship of abrasive and bond are actually measured into the wheel at the time of moulding. As a result, variations in the volume structure have been materially reduced as shown in the following comparison :—

	Finished Stock 20-R Puddled	Finished Stock 20-R 7 Controlled Structure
Total variation between six wheels	2.7%	.5%

The wheels from which the data given in the above table were obtained were taken from stock and represent the average product which is normally shipped to customers, and the point to be noted is that the total variation in volume per cent. of abrasive has been reduced by approximately 80%.

B Bond.

This is an improved type of vitrified bond and differs from the regular type of vitrified bond in several respects. It produces a cooler cutting wheel and is less harsh in its action on diamonds used for truing. It is not subjected to changes due to temperature variations which, over a period of time, tend to lower the grade of the regular bond product. It gives improved cutting action which allows harder grades to be used.

B bond gives a wheel uniform and stable composition throughout. Each grain is held as securely as the next. More cutting points are constantly presented to the work than with standard vitrified bond. Thus the stress of grinding is more evenly distributed over many cutting points, giving more even wheel wear and a material decrease in number of dressings.

General.

With the combination of B bond and controlled structure we have made a great advance toward the ultimate goal—grinding wheels which are uniformly constructed throughout and which can be very definitely duplicated. B bond is not alone in improvement. The bakelite, shellac, and rubber bonded wheels have all improved in many respects, helping materially the development of better wheels for operations which demand organic bonds.

Sheffield and its immediate district manufactures a very large range of steel products and it is difficult to include every type of grinding operation in this short paper. A representative selection has therefore been made.

Grinding by hand on a sandstone was the main method of removing surplus metal in the past and when using this medium, it was necessary to use great pressure of the work upon the wheel in order to obtain abrasive action. When artificial wheels came, some workers persisted in using the same amount of pressure and found themselves in difficulties through the cracking of delicate hardened tool cutting edges or the drawing of the temper and consequent softening of an already hardened article.

The sandstone is generally of soft bond and in order to obtain abrasive action it is necessary to use heavy pressure in order to dislodge grains of silica from the cutting face of the wheel. These grains roll between the wheel face and the work being ground and thus cause abrasive action.

The cutting action of the artificial wheel is exactly the opposite. In this case, each grain is securely held in its position by the bond and it is the designed duty of each grain first to penetrate the work, to stand up until the friction becomes too great, when cutting its respective chip, and then to shatter and disclose more sharp particles ready to carry on the work.

In order to obtain long life in a wheel and to ensure free cutting, light pressure should be the rule. Should heavy pressure be used, the wheel face usually becomes coated with metal and discolouring of the work may result on unhardened work, thus necessitating the excessive use of the wheel dresser and shortening the wheel life. On hardened work excessive pressure will often cause sensitive hardened tools to develop surface cracks through generated heat and almost always interferes with the hardness of cutting edges.

During hand grinding operations a wheel is supposed to carry on its periphery a thin film of coolant, generally water, to assist in dissipating generated heat. This method was probably in order when wheels of dense structure were used but with modern wheels with open structures purposely designed to carry a supply of coolant, the thin layer is apt to be thrown off by centrifugal force, which causes the grinder in effect to be working on a dry wheel. It is

suggested that it will be to the advantage of all users to devise some method of supplying a heavier flow of coolant, properly directed to the point where the actual grinding action is taking place. This heavy flow, together with light pressure of the work upon the wheel, will greatly eliminate troubles due to excessive generation of heat. Possibly a pipe, perforated with small holes, might be fixed under and in front of the horsing and a suitable guard to keep the operator dry would supply all that is necessary. Distortion of the work, the drawing of delicate edge temper or the surface cracking of hardened blades would be much reduced and possibly eliminated altogether.

Grinding Cutlery by Hand.

The hand grinding of cutlery is at present, almost always performed on wheels of silicate bond. This class of work includes pen and pocket knife blades, table blades, scissors, and surgical instruments.

The system of working in Sheffield whereby the operator first grinds the blades from the rough blank and then proceeds to glaze and polish, seems to be in need of revision. Where large production is desired faster cutting wheels are necessary and given an efficient coolant supply, harder wheels could be used giving more economical wheel life. It would mean more polishing operations but with one or two men rough grinding and others each in turn polishing successively finer, it is suggested that a large flow of finished blades would result. The sizes of the wheels in use to-day are 28 in. × 3 in. and 24 in. × 2½ in. for pocket knife blades and medium size scissors and the grain and grade is 80-O silicate. For pen blades and small scissors the usual grain and grade is 100-O silicate.

Table knife blades are ground upon wheels 42 in. × 6in. grain and grade usually 60-N silicate. Table blades are also ground cylindrically with vitrified wheels. In this case an efficient heavy flow of lubricant ensures fast cutting and the dissipation of heat generated. On Hemming type machines, which use a face grinding wheel, shellac wheels were at one time generally used. These have been largely replaced by wheels of bakelite bond. This type of grinding does not seem to be used as extensively as was formerly the case.

Scythes and Sickles.

Scythes are usually ground by hand on wheels of silicate bond and here the question of a greater flow of lubricant seems to apply with more force. Plate scythes, pressed from the sheet, are regularly ground without difficulty upon artificial wheels, but crown scythes which have a wrought iron back and a hardened steel cutting edge still create difficulty on account of the generated heat cracking the hardened steel edge. There is also a tendency

for the soft iron to load the cutting face of the wheel. Wheels 48 in. × 9 in. are often used for scythe work and the grain and grade varies around 50-M silicate. For the " bearding " operation, that is, the smoothing of the cutting edge after rough grinding, a harder wheel is necessary and 46-O silicate gives good results. For work on sickles a good " mending " stone is 60-M silicate.

The life of a good scythe wheel is usually two to two and a half years. They have been known to last longer in experienced hands. The work is much cleaner and much " hanging " of sandstones is eliminated, as these sometimes give a life of only a few weeks. A segmental wheel 48 in. × 9 in. is in use in a local works for scythe grinding. This is fitted with " B " bond segments of vitrified type. It is an experiment which is not yet completed.

Saws.

Circular saws for wood and metal cutting have been ground for some years on a segmental wheel. This wheel is still in use. In another concern, pit saws and similar types have been the subject of active grinding experiments. The wheels used have cut coolly and freely and have left a very good finish on the work, while giving fast production. In addition to the operations mentioned, segmental wheels have been used on hand file grinding operations and for agricultural tools, spades, and shovels and on similar work.

Edge Tools.

For some years the adaptation of the artificial wheel to the bevelling of edge tools caused difficulty because of the excessive amount of metal which had to be removed from the straight cropped hardened blank. This was not helped by the tendency of the operators to use excessive pressure of the work upon the grinding wheel. There has since been an improvement in this direction but there is still need for a more efficient coolant supply.

In one local works, reaper sections have been successfully ground on solid B bond controlled structure wheels. The work was cleanly ground without discolouration or burning.

File Grinding by Machine.

The use of the sandstone for machine grinding files is not prohibited by the Factory Regulations controlling local machine grinding conditions. This fact was rather an incentive to attempt to do this work with segmental wheels. A local installation can now be shown to anyone interested where there are a number of these wheels in constant use and where the entire production is dependent upon the work done by these wheels. The sizes of segmental wheels in use are 60 in. × 12 in., 48 in. × 12 in., 40 in. × 12 in. and 36 in. × 12 in. wide. These wheels grind files

from 4 in. flat, all sizes of parallel, hand, square, three-square up to 20 in. tram files. The finish left on the files is so good, that with a few exceptions, a " stripping " operation is entirely eliminated. The files are sent straight to the cutters exactly as left by the grinding wheel. The flat sides of half-round files are dealt with in the same manner.

The machines used are the old Oxley and Winnard types, which have been thoroughly overhauled and put into good mechanical condition. The old hit and miss cam motion used for the side oscillation of the wheel on its spindle has been removed and a positive mechanical side oscillation has been fitted, which will allow the stroke to be varied if necessary. Actually the wheel now makes about 30 passes sideways per minute. A new wheel truing device has been installed which will keep the wheel cylindrical and correctly true the wheel face should there be any tendency to slight grooving.

Another vital improvement made enables the wheel to follow exactly the contour of a hand or taper file. This consists of spring bearings upon which the table runs. This device is simple in construction and is covered by patent specification. Its use will be permitted to all who have this kind of work to do.

By these means the old time grinding machine has been turned into a modern producing medium. The work is cleaner and easier and a production increase of from 33⅓% to 50% over that if the sandstone has been obtained and is regularly maintained. One great advantage is that the operators themselves are now freed from the scourge of silicosis.

In operation, the operator lightly trues his wheel at the commencement of a day's run to ensure that the wheel is perfectly round and the face straight and free from grooves, puts on just sufficient depth of cut to do the necessary work and then proceeds to grind his work as usual. Throughout the day it is not necessary to give any attention to the condition of the wheel or to interfere with the depth of cut. The latter is automatically adjusted by the spring bearings upon which the table runs. The whole of the operator's time can therefore, be devoted to the production of satisfactorily ground files.

One type of machine file grinding operation has not been touched upon. This concerns the grinding of round and half-round files. Experiments are now proceeding in this direction also and wheels are now being manufactured which it is believed will eliminate the use of the sandstone.

The Segmental Wheel.

The early type, No. 4, consisted of a steel centre around which the segmental blocks were securely bolted. This type is still used for

some sizes and one size is in use locally, engaged in machine grinding files. When replacements are required, it is necessary to return the steel centre to the factory to have new segments fitted. This is not the case with the No. 6 type. When initially supplied as a new installation, the wheel is sent out complete with boss and flanges, and it is merely necessary to slide the complete wheel upon a keywayed shaft of the correct size. It is then secured in position by means of the spindle nut. These wheels do not require separate flanges. When replacement become necessary, a new replacement unit is requisitioned and this reaches the purchaser in the form shown upon the screen. It is merely necessary to rebolt the original boss and flanges to have a new wheel ready foı operation in a short time.

Owing to physical and manufacturing conditions, a 40 in. diameter wheel is the largest which can be supplied in vitrified type. Wheels of this type are regularly supplied for some local operation and wheels as large as 54 in. diameter have been used, these being of silicate bond.

With the segmental wheel limitations of size do not exist and wheels up to 72 in. diameter have been installed in Sheffield. At present the largest wheels in use here are 72 in. diameter by 10 in. wide. This wheel is safe from breakage and its construction is an engineering achievement. It is not an experiment and has been used locally for the past twelve years. The clamp bars secure the full width of the wheel. Each block composing the unit is bolted solidly in two places to the flanges, and there is a recess on the inside of the flanges in which the ends of the clamp bars fit, thus ensuring that the wheel is cylindrical within a few thousandths of an inch when ready for mounting.

The new B bond segments are fitted with the advantage of very exact duplication in grain and grade. The controlled structure feature enables the wheel action to be closely adjusted to the work to be done.

When a new replacement unit is mounted, the retaining bands are removed and returned with the old clamp bars for credit to be given. The hub and flanges become part of the machine and it is not necessary to repurchase these once they are installed. All segmental wheels are carefully built in special fixtures and size for size, the replacement units are interchangeable.

Tool Room Work—Tool and Cutter Grinding.

The B bond controlled structure wheel is extensively used locally for all classes of tool toom work. It is very cool and free cutting and retains a formed shape for a longer period than is usual with other wheel types. These wheels are made in all the usual tool and cutter grinding shapes.

Trouble is sometimes experienced in grinding tipped tools of the

tungsten-carbide types. For this operation the ordinary tool grinding wheels are not suitable and it has been necessary to develop a new type of grain which is very hard. The wheels used for tungsten-carbide should be of a very hard grain, in successively fine sizes with a comparatively soft bond. The use of the correct wheels will ensure cool free cutting and the elimination of fine cracks from the cutting edge of the carbide tip.

In order to ensure that the carbide cutting edge is smooth and sharp, a lapping operation is usually considered necessary. For this work, diamond wheels have been developed. These have genuine Bort diamonds incorporated in a suitable bond. Diamond wheels are supplied for internal grinding, cutting-off, plain shape for finishing and in cup shape for burnishing, for instance, the teeth of cemented carbide inserted tooth milling cutters. Lapping reamers is another suitable job.

Fettling.

Fettling castings and billets at 5,000 s.f.p.m. is very general in this district. The tendency is to use grinding wheels which are on the hard side under the mistaken impression that a wheel which has a long life must be the cheapest producer. This is not always the case.

When attention is directed to the tonnage ground by the wheel and the time taken to do this work it will often be found that a softer and more free cutting wheel will prove cheapest. The life has been shorter but it has been cutting faster. The aim should be to obtain the lowest abrasive cost per pound of metal removed. One local concern, being concerned at the size of their grinding wheel bill, but aware that these wheels are often subjected to abuse in working, decided to arrange a test of cutting efficiency with wheels operating free of the human element.

An electrically driven swing frame grinding machine was installed in the machine shop and a weight of 50 lb. hung upon the wheel head. All types of competitive makes of wheels were supplied for test. A large block of manganese steel was obtained and the system used was that each wheel was to be tested for two hours only in turn, the wheels being weighed both before and after grinding, as was also the case with the manganese block.

Side oscillation of the machine when at work was provided by a large lathe then standing idle, to the face plate of which was secured a steel connecting link. The other end of the link was fastened to the wheel head. Both grinder and lathe were set in motion and the test proceded. The results disclosed that 16-Q which had been standard for some years was better than any competitive wheel tested and it removed 8 lb. of metal per hour, for a loss on diameter of ¾ in. A better wheel was found, however, as 16-P8B removed

11.5 lb. of metal per hour for a loss of ⅜ in. on diameter. The 16-P8B wheel was then sent to the grinding shop and used in the ordinary way. Its " life " down to 8 in. diameter was forty-five hours.

It is usual to find locally that wheels revolving at 5,000 s f.p.m. are more useful for grinding high speed steel billets and to use wheels of bakelite bond revolving at 9,000 s.f.p.m. for stainless steel billets and slabs.

A point regarding the use of wheels at high speed might be mentioned. It had long been known that a softer grade of wheel than usual revolved at high speed would be a better producer than a hard wheel run at slow speed. The difficulty was that it was not considered safe to revolve the ordinary vitrified wheel at a speed higher than 6,000 s.f.p.m. When synthetic cements of great strength became available, the way was paved for the use of such wheels at 9,000 s.f.p.m. Many users, however, are losing the advantages to be obtained from high speed grinding because they have reverted to the old system of using harder and successively harder bakelite wheels in order to obtain long wheel life.

Roll Grinding.

Very high finish can be obtained on rolls when the correct methods and suitable wheels are used. Each roll grinding problem must be considered on its merits and when requested, abrasive engineers who are skilled in this kind of work, are always available to assist in the successful solution of this difficult problem.

(*The lecture was illustrated by lantern slides.*)

Discussion.

Mr. F. Williams (Section President, in the Chair): I am sure you have all listened with very much interest to Mr. Lee's paper, and I hope you will be able to raise quite a few useful questions. There is a question I should like to ask myself. Mr. Lee spoke of "Norbide." I am not at all clear whether he considers that this is a good substitute for diamond wheels, particularly if they are so much cheaper than the diamond wheels. Is it a suitable substitute ?

Mr. Lee: The "Norbide" at present cannot be made into wheels; it is used as an abrasive, and as a moulded product the powdered "Norbide" is used as a lapping medium, and takes the place of diamond dust.

Mr. Barber: It would be interesting to everyone if Mr. Lee could give us some comparative figures between the efficiency of the artificial abrasive wheel and the natural sandstone on some of our local trades. One thing in particular occurs to me, and that is as regards file grinding. Perhaps, rather naturally, the exponent of the artificial wheel would claim that it does the work equally well. It may do, but it would be rather interesting to have the lecturer's view. We have the benefit sometimes of the Sheffield grinder's views, which are rather in favour of the sandstone. It would be of interest to have the views of the artificial wheel specialist on that particular operation. The more familiar engineering applications of the wheel are known to most of us, and of course there are no substitutes for them. In these older Sheffield trades, I do not think it has been definitely cleared up whether the artificial wheel is more economical and advantageous in its work as compared with the other. Perhaps the lecturer could give us a little information on the point.

Mr. Lee: Mr. Barber raised the point of the artificial wheel against the sandstone. Speaking generally, on various jobs, the life of the artificial wheel ranges from 10 sandstones, to, in some cases, 30 sandstones. In particular, with regard to file grinding, we usually average 10 to 16 sandstones. The production, as I have said in the paper, is increased by $33\frac{1}{3}$ to 50% on files. We have actually tested files from the grinding wheel and from the sandstone, and we have been told by the file manufacturers that the file blanks from the wheel are in better condition for cutting than from the sandstone, as there is a slight hardness from the sandstone. Another advantage which the wheel has, is that in most cases stripping, which is an entirely separate operation with the sandstone, is not considered necessary by some file manufacturers. I think I have answered most of Mr. Barber's questions. There is

one point I should like to emphasise, particularly with regard to file grinding, and it also applies to some of the other sandstone replacement jobs. We are rather at a disadvantage when we are given a machine which is anything up to 100 years old, and we are asked to put a modern wheel on it. I do think that on some of the Sheffield jobs, such as saw grinding, a modern machine might be developed, and not merely a reconstruction of an old machine which has been in use for say 100 years, should be used.

Mr. Williams: There is one point I would like to ask, and that is, the comparative cost of these stones—the artificial stone and the sandstone.

Mr. Lee: That varies, of course, with the class of sandstone used. A 60 in. sandstone varies from £4 to about £12, and a 60 in. abrasive wheel of the same thickness would be about £120. On most jobs we have to average at least 10 times the life of the sandstone to make it a paying proposition. On some we have got to go as high as 20 times, and on some jobs, the customers are satisfied with seven or eight times the sandstone life.

Mr. Barber: These figures are very enlightening, and it is quite clear that the economy of the artificial wheel is going to depend to a great extent on the amount that is razed off each time. Could we have the lecturer's opinion on the method of razing such a large artificial wheel? Would he use a diamond, or a Huntingdon dresser? It is going to be a matter of first-class importance, especially to the people in Sheffield.

Mr. Lee: As far as machine file grinding is concerned, we have found that it is only necessary to dress the wheel once a day. Some of the special trades have found it is necessary to do it a little bit oftener. We use the Huntingdon type of dresser, and it has been found very satisfactory. The usual operation is, the man trues his wheel up once a day, and he probably takes off $\frac{1}{16}$ in. off the diameter, and that is adequate for the day's work.

Mr. Barber: Is the Huntingdon dresser you use mechanically held?

Mr. Lee: On the file grinding machine, there was an arrangement for 3 in. or 4 in. diameter cutters. The same arrangement has been tried out, and the dresser is at the back of the wheel, and it is fed in by a slide and a screw.

Mr. L. R. Evans: In all the cases of the machines which Mr. Lee has shown tonight, there is no provision for increasing the speed of the wheel as it wears down. Does Mr. Lee consider that an important thing to do?

Mr. Lee: That is a very important item, though of course it varies in relationship to the diameter of the wheel. On the large segmental wheels which we have been discussing, in Sheffield we do increase the speed of the wheel every inch of diameter that is worn

down. When you get down to wheels 12 in. and 8 in. diameter, it is sometimes inconvenient to increase the speed. It is very important that the whole speed should be kept constant, and if you took a test in your own shop, you would be amazed at the increased wheel life you would get from the increase in the speed as the wheel wears down.

MR. S. CLOWES: I should be glad if Mr. Lee would outline his system for producing a mirror finish on a roll of say about 40 in. diameter × 6 in. on the barrel.

MR. LEE: I do not think there is a system for producing a mirror finish on a roll such as you describe. The usual method employed, is to start off with a 60 or 80 grit wheel, and either one or two polishing wheels, but the major part of getting what is a really good mirror polish, is purely dependent on the skill of the man, and the machine, and I am afraid I cannot give you any hints on that. It is purely a matter of the pressure which is exerted on the wheel. A certain pressure must be built up between the wheel and the work, and that pressure depends on the type of the machine, and the type of tool which is being ground.

MR. CLOWES: What I was trying to get at is the number of wheels Mr. Lee would have to use to get a certain standard of mirror finish.

MR. LEE: I think that is a question which has been creating some discussion recently. There is not a standard of mirror polish. We get asked for a mirror polish for work which does not really require it, and what one firm calls a mirror polish, another firm calls a commercial finish. To produce a commercial finish on a hardened steel roll, I should say rough out with anywhere between a 36 and 80 grit, semi-finish with a 120, and finish with a 300 grit wheel.

MR. CLOWES: I was really referring to an iron roll.

MR. LEE: We have found that some firms are quite content with an 80 grit finish on a roll of that kind, and others go up to 150. We do not go beyond that on iron rolls.

A VISITOR: I should like the lecturer to tell us the cost of the large segmental wheels. He gave us a figure of £120. Is that the cost of the wheel with the steel centre. What do the centres themselves cost?

MR. LEE: I gave a cost of £120. That is the cost of a 60 × 12 wheel—the replacement unit. The cost of the steel centre is round about £40 to £50.

MR. WILLIAMS: So your initial cost may be in the region of £160 or £170.

MR. LEE: I should say somewhere about £150.

MR. SPORSHOTT: During the course of the lecture, Mr. Lee showed us a wheel cutting off the ends of a drill. There is a good deal of that done in Sheffield to-day, and I should like Mr. Lee to

confirm this, or otherwise. Could Mr. Lee give us his idea of the speed that that wheel should run at, and also the horse power required to drive that wheel, and the maximum diameter of material he would consider that that wheel should cut.

MR. LEE: I take it, Mr. Sporshott, that you are referring more to the cutting off than to just that particular operation. Cutting off is a job which is very interesting to many people in these days, and we are not quite as far ahead in this country as they are in the States. Cutting off wheels 12 in. and 16 in. diameter, are regularly used for bar work, and the effective limit is about 1½ in. diameter. We have not found it advantageous to go above that so far. As regards the horse power, I heard one case in Sheffield a few weeks ago, where a 5 h.p. motor was working a 12 in. cutting off wheel, and it was found that there was a slight lag as the bar was being cut through. A 7 h.p. motor was put on, and a big improvement was found, but even the 7 h.p. motor was found to be on the small side. The work in this particular case was up to ¾ in. diameter.

MR. CLOWES: Is there any cutting lubricant which is really good for the job? What effect has soda got on your 600 grit wheel?

MR. LEE: We do not like a great deal of soda in the compound for the type of wheel we have to use for a mirror polish. If soda can be avoided, it is to the advantage of the job. We prefer the paraffin type of lubricant for lapping, and water for mirror polishing.

MR. EVANS: About the cost of these wheels, Mr. Lee has shown us how they have been made, but I have always wondered why they have been so costly. The question of cost has always been one which has interested me.

MR. LEE: Well, I did show some slides showing the manufacture of the abrasive, which of course would lead you to think that that is rather an expensive proposition in itself. A tremendous amount of electric current is required to fuse the clays and cokes into the hard abrasive material which we use, and of course there is a lot of work on the abrasive itself before it gets near the grinding wheel factory. The manufacture of grinding wheels is still rather an expensive proposition. The wheels have to be very carefully checked, and included is an expensive burning operation, with a certain amount of expense on rejects. I do not know exactly what I can say, except that the cost of a grinding wheel is not an exorbitant one by any means. To manufacture grinding wheels, you have to use a good quality abrasive, and if you reckon it up by weight, you will find you are not paying a very high price.

A VISITOR: I should like to touch on the question of the balance of the wheels. When a new wheel is fitted to a precision machine,

it may run truly on the periphery for a while, but in a short time, it may get out of balance and cause a lot of trouble. I should like to ask Mr. Lee what is the reason for this. Is it because of the lack of uniformity of the constituents of the wheel? What steps are the manufacturers taking with regard to this out-of-balance

MR. LEE: The balancing of wheels, of course, is a subject that causes all of us a lot of trouble from time to time. I should like to point out that most grinding wheel manufacturers have three or four grades of balance. Usually, from the size and specification of the wheel, we can tell pretty well what the job is. All cylindrical and surface grinding wheels, with the exception of cup wheels are made to perfect balance. I should like to ask you to make sure that your machines are not at fault before you blame the grinding wheel manufacturer. I had six returned as being out of balance, and also out of truth on the sides. All the wheels were absolutely perfect in every degree, and I can assure you that was the case, because I saw the actual tests on them myself. As regards the balance weights, I should like to say that although the wheel is perfectly balanced when it is mounted, when it wears down, there is a tendency to get out of balance, and a balance weight should be used in that connection.

A VISITOR: Regarding tungsten carbide, I think it would be of considerable interest if Mr. Lee could enlarge on this point. Even using the special wheels at correct speeds, the time is rather long, and if Mr. Lee could give us a brief outline of modern practice together with, say, a comparative figure for grinding a tool of equal section in super high speed steel, and again, in tungsten carbide, it would be of considerable interest.

MR. LEE: I am afraid I cannot give off-hand, a comparative time for grinding high speed and tungsten carbide. Perhaps some of the people in the room will be able to do that. The general practice is to have say three or four wheels, one for cutting back the steel shank, and it is very important that the steel shank should be cut back before grinding of the tungsten carbide is attempted. If this is not done, the first wheel would be glazed up, and you would not get a free cut on the wheel at all. Following the shanking wheel, we use either a 46 or 60 grit wheel for roughing, 100 grit wheel for finishing, and a 220 wheel for burnishing. In tungsten carbide, you are dealing with a hard material, which is not so very much softer than the wheels you are using. One rather important point is that a number of people are content to just rough and finish, and then they are rather disturbed at the very short life they get from the tool. Burnishing is a very important factor, and it should be done wherever it is possible.

MR. WILLIAMS : I think anybody who uses tungsten carbide tools would find a great advantage from finishing the edge on a diamond wheel. You get far less split than if you take them off the ordinary finishing wheel.

MR. BRAIDWOOD : I should like to return to the question of the speed of grinding wheels. I think Mr. Lee mentioned that the speed of the stone should be increased *pro rata* to the inch per reduction of diameter of stone. On a recent machine installed in Sheffield, the stone was 30 in. diameter, but there were only two variable speeds. The user suggested putting on a variable speed motor to keep the speed to a constant standard in relation to the diameter of the stone, but the makers of the machine turned this matter down as being impracticable.

MR. LEE : When I was referring to the increase in speed, I was referring to the large segmental wheels. The wheel Mr. Braidwood mentioned, is 30 in., and it may not be practicable to increase the speed. Regarding the point as to the reason the matter of increased speed was turned down by the makers of the machine, I can only say that the manufacturers of the machine evidently thought that the increase in wheel life would not compensate them adding the new equipment to give an increased speed. From the wheel life point of view only, the increased speed is certainly desirable, but there are other factors on the machine which might negative that altogether.

MR. HARRISON : I would like to ask Mr. Lee what grade and grit he would recommend for grinding chilled cast iron castings. I remember some years ago, I had a lot of difficulty in grinding certain chilled iron castings. The machine tool manufacturers came along, and said that we wanted a grinding machine for the job. They sold us one, but they did not tell us where we could get a decent grinding stone to do the job. The castings in question were costing 10d. each for stone wear alone, and it resulted in this particular company having to go to Germany to get a stone which was suitable for the job. If I remember correctly, the stone supplied was a bauxolite composition stone. There wasn't a firm in this country producing a stone suitable for the job. I may say that the particular machine in question was a high precision surface grinder, and the segments were of the disc spaced type.

MR. LEE : I am rather surprised at what Mr. Harrison said. There are a number of machines in this district doing similar classes of work, and as far as I know, there has not been a great deal of trouble in the grinding. We recommend a coarse bond wheel for that type of job, depending on the quality of the cast iron. 24 to

30 grit, grade from H to J. As I have said, there are quite a number of these machines doing similar classes of work, and I do not think any difficulty has been experienced at all. The price you mention is certainly out of all reason.

Mr. Harrison: The price was brought down to 1d., and we were not satisfied with that.

A vote of thanks to Mr. Lee concluded the proceedings.

ANNUAL REPORT

and

ACCOUNTS

For the Year ended 30th June, 1936.

To be presented at the

ANNUAL GENERAL MEETING

2nd October, 1936,

At Institution Headquarters,
British Industries House,
Marble Arch, London, W.1,
at 7-15 p.m.

THE INSTITUTION OF PRODUCTION ENGINEERS.

BALANCE SHEET AS AT 30th JUNE, 1936.

LIABILITIES.	£	s.	d.	£	s.	d.
SUNDRY CREDITORS				454	1	2
SUBSCRIPTIONS RECEIVED IN ADVANCE...				19	5	6
Lord Austin Prize Fund	52	10	0			
Building Fund	156	5	0			
Hutchinson Memorial Fund	37	12	6			
				246	7	6
INCOME AND EXPENDITURE ACCOUNT:						
Balance at 1st July, 1935	1598	10	11			
Add Excess of Income over Expenditure for the year	311	12	4			
				1910	3	3

ASSETS.	£	s.	d.	£	s.	d.
FURNITURE, FITTINGS, AND PLANT at cost less amount written off:						
Balance at 1st July, 1935	£209	14	3			
Additions during the year	436	14	0			
	646	8	3			
Less amount written off	129	9	8			
				516	18	7
INVESTMENTS at cost:						
£2077 5s. 5d. 2½% Consolidated Stock				1559	16	3
(Market Value £1776 1s. 4d.)						
SUNDRY DEBTORS				203	19	5
SUBSCRIPTIONS IN ARREAR, *not valued.*						

				CASH :						
				At Bank	346	17	9			
				In hand	2	5	5			
								349	3	2
	£2629	17	5					£2629	17	5

AUDITORS' REPORT.—We have audited the above Balance Sheet dated the 30th June, 1936, and we have obtained all the information and explanations we have required. In our opinion such Balance Sheet is properly drawn up so as to exhibit a true and correct view of the state of the Institution's affairs according to the best of our information and the explanations given us and as shown by the books of the Institution.

Aldwych House, Aldwych, London, W.C.2.
5th September, 1936.

(*Signed*) C. H. APPLEBY AND COMPANY, Auditors.
Chartered Accountants.

(*Signed*) THOS. FRASER, *Chairman of Council.*
(*Signed*) WALTER G. KENT, *Chairman, Finance Committee.*
(*Signed*) R. HAZLETON, *General Secretary and Treasurer.*

THE INSTITUTION OF PRODUCTION ENGINEERS.

Income and Expenditure Account for the Year ended 30th June, 1936.

Dr. | Cr.

Dr.	£	s.	d.
To Salaries	962	3	9
,, Rent, Lighting, Heating and Cleaning	265	15	11
,, Local Section Expenses	432	15	4
,, Printing, Postages, Stationery, Telephone, and Certificates	293	7	9
,, Printing, Postages, and Stationery—Journal and Bulletin	682	14	6
,, Staff Travelling and Expenses of General Meetings	78	4	6
,, Professional Charges, Insurances, and Income Tax	54	1	1

Cr.		£	s.	d.
By Subscriptions received :				
Current	£2395 12 0			
Arrears	103 6 0			
		2498	18	0
,, Interest on Investments		51	13	1
,, Receipts from Sales and Advertisements of Journal		741	6	1

	£	s.	d.		£	s.	d.
„ Library	9	6	2				
„ Examinations	34	19	3				
„ Annual Dinner, less receipts ...	10	14	2				
„ Miscellaneous	26	12	9				
„ Amount written off Furniture, Fittings, and Plant	129	9	8				
„ Balance, being Excess of Income over Expenditure	311	12	4				
	£3291	17	2		£3291	17	2

ANNUAL REPORT FOR 1935-36.

Membership.

The membership at the end of June, 1936, was as follows :—

Honorary Members	3
Ordinary Members	511
Associates	32
Associate Members	527
Graduates	235
Affiliates not already included in other grades	22
Affiliated Firms	30
	1,360

Two hundred and twenty-five new members were added to the Register during the year. Five members died, fourteen resigned, and forty-one lapsed. The members whose deaths have to be recorded, in addition to that of Mr. J. H. Garnett, referred to in the previous Annual Report, were Messrs. A. Gigli, R. R. James, W. H. Sumner, and A. Yorke.

Finance.

The annual accounts show that the Institution continues in a sound financial position. It is hoped that the Chairman of the Finance Committee, Sir Walter Kent, C.B.E., will shortly be able to resume active duty after a long period of convalescence following the serious operation from which he has now, happily, recovered.

New Sections.

During the year a new Graduate Section was formed at Coventry, and the Inaugural Meeting of the London Graduate Section was held in October, 1935. In April, 1936, the first Student Centre of the Institution was opened by the President, Lord Sempill, at Loughborough College.

Lord Austin Prize.

The winner of the Lord Austin prize for best attainments at the 1936 Graduateship Examination was Mr. R. A. P. Misra, St. Albans, Herts.

Medal for Best Paper.

The medal for the best paper by a member during the 1935-36 Session was awarded for the paper on " The Relation of Cemented Carbide Tools to Modern Production," by Mr. E. W. Field, Member of Council, and the late Mr. J. H. Garnett.

The Production Engineers Appointments Board.

The Council, on behalf of the Institution, has given official recognition to the Production Engineers Appointments Board set up early in 1936 to deal with appointments for qualified production engineers. Membership of the Board and its subscribers are limited to those who are members of the Institution.

Memorial to the late Mr. R. H. Hutchinson.

In March, 1936, a memorial portrait in oils of the late Mr. R. H. Hutchinson, Past-President, painted by Mr. William Carroll, was unveiled at Headquarters by Mr. J. A. Hannay. The ceremony, presided over by Lord Sempill, was very well attended. In addition to the portrait, a Hutchinson Memorial Medal is to be presented annually for the best paper by a Graduate. The Council thanks the many members who subscribed to the memorial.

Lectures and other Activities.

Lectures last session continued to be well attended, though some Sections reported that owing to increased industrial activity leading to overtime work, many members and visitors were unable to get to meetings. The number of Works Visits and Social Functions is still growing.

Lord Austin, K.B.E.

On behalf of the Institution, the Council has conveyed to Lord Austin, K.B.E., Past-President, Member of Council, hearty congratulations on his elevation to the Peerage.

Thanks to Lecturers.

We wish to thank our many lecturers for their invaluable services during the past Session.

The President.

We are pleased to report that Lord Sempill has kindly undertaken to serve as President for the coming year.

Gift to the Institution.

Thanks have been conveyed to Mr. J. D. Scaife, Past-President, for the gift of a bronze bust of Cecil Rhodes.

Printing Department.

This has been re-equipped to enable it to deal more efficiently with our printing.

Assistant General Secretary.

Mr. Marsden, after nearly five years' service on the Institution staff at Headquarters, has been appointed Assistant General Secretary.